TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

FORTY-SECOND YEAR, 1903–1904.

BOSTON, January 15, 1904.

THE 589th regular meeting of the SOCIETY OF ARTS was held in the Lowell Building, on Friday evening, January 15, at eight o'clock, Professor Walker in the chair. One hundred and fifty-five persons were present.

After the minutes of the previous meeting had been read and approved, Mr. W. E. Parker was elected to Life Membership in the Society.

Professor J. W. Richards, of Lehigh University, addressed the Society on "The Use of Electricity in Metallurgy."[1]

After a discussion of the paper a vote of thanks was tendered the speaker, and the meeting adjourned.

BOSTON, January 28, 1904.

The 590th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, January 28, at eight o'clock, Mr. Munroe in the chair. Sixty-five persons were present.

[1] TECHNOLOGY QUARTERLY, 17, No. 1, March, 1904, pp. 22–36.

After the minutes of the previous meeting had been read and approved, Dr. F. W. Clarke, chief chemist of the United States Geological Survey, addressed the Society on "The Chemical Work of the United States Geological Survey."

A vote of thanks was tendered the speaker, and the meeting adjourned.

BOSTON, February 11, 1904.

The 591st regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, February 11, at eight o'clock, Professor Cross in the chair. About four hundred persons were present.

Mr. George F. Kunz addressed the Society on "The Action of Radium and Ultraviolet Light on Minerals and Precious Stones." The lecture was illustrated with a number of experiments.

A vote of thanks was tendered the speaker, and the meeting adjourned.

February 26, 1904.

The 592d regular meeting of the SOCIETY OF ARTS was held in Room 6, Lowell Building, on Friday evening, February 26, at eight o'clock, Professor Talbot in the chair. Ninety-five persons were present.

After the minutes of the previous meeting had been read and approved, Dr. Samuel P. Sadtler addressed the Society on "The Preservative Treatment of Wood."[1]

A vote of thanks was tendered the speaker, and the meeting adjourned.

March 10, 1904.

The 593d regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 10, at eight o'clock, Professor Cross in the chair. One hundred and five persons were present.

After the minutes of the previous meeting had been read and approved, Mr. Earle L. Ovington and Mr. Herbert Dabney were elected to Associate Membership in the Society.

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[1] Below, pp. 129–144.

Professor E. F. Nichols, of Columbia University, then addressed the Society on "The Measurement of the Heat of the Stars."

A vote of thanks was tendered the speaker, and the meeting adjourned.

March 24, 1904.

The 594th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 24, at eight o'clock, Professor Niles in the chair. Forty-five persons were present.

Dr. Cyrus Adler, librarian of the Smithsonian Institution, addressed the Society on "The History and Work of the Smithsonian Institution."

After the Society had extended a vote of thanks to the speaker, the meeting adjourned.

April 7, 1904.

The 595th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 7, at eight o'clock, Professor Lanza in the chair. Three hundred persons were present.

The following-named, graduates of the Institute, were elected to Associate Membership in the Society: Mr. Lammot du Pont, Mr. Arthur E. Nash, Mr. James C. Howe, Mr. Richard E. Dow, Mr. G. A. Hall, Mr. E. S. Foljambe.

Professor C. L. Norton then addressed the Society on "The Recent Conflagration in Baltimore."[1]

After the Society had extended a vote of thanks to the speaker, the meeting adjourned.

April 28, 1904.

The 596th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 28, at eight o'clock, Professor Clifford in the chair. About one hundred persons were present.

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[1] Below, p. 148.

After the minutes of the previous meeting had been read and approved, Mr. George E. Roberts, director of the United States Mint, addressed the Society on "Coinage and the Precious Metals." The speaker gave an historical account of coinage and described the methods in use in the United States Mints. A large number of lantern slides of ancient coins was shown. A discussion, in which a number of members took part, followed the address.

A vote of thanks was tendered the speaker, and the meeting adjourned.

JAMES F. NORRIS, *Secretary.*

THE PRESERVATIVE TREATMENT OF WOOD.

By SAMUEL P. SADTLER, Ph.D., LL.D.

(Read February 26, 1904.)

Wood, because of its universal distribution over the surface of the globe, and equally because of the ease with which it can be shaped and adapted to purposes of construction, has been for both civilized and uncivilized man the most convenient and widely used material for a great variety of purposes. But it obviously has its limitations. Being composed of organic tissue, it does not possess the power of withstanding atmospheric influences with alternations of heat and moisture so well as mineral matter like stone, or even as some of the metals.

The nature of the changes that wood tends naturally to undergo, unless prevented by some form of treatment, has been the subject of widely divergent theoretical views. The destructive changes, summarized as decay in wood, were stated by the great German chemist, Liebig, to be due to a form of slow combustion, which he called *eremacausis*. The processes of change, in his view, were induced by oxygen, much as iron changes to rust. He stoutly denied that bacteria, fungi, or other living agencies had anything to do with decay. Not until the publication of the researches of Pasteur and his school was it understood that the changes which accompany decay are due to the activity of lower animals and plants. These low organisms, living on or within the substances, use a portion of the same for food, and by removing some of the elements from the substratum, they break up the complex chemical compounds. This results in the liberation of various gases and in the phenomena which are known collectively as rotting or decay.

The living organisms which cause decay of timber may be insects, bacteria, or fungi. Insects bore into sound timber, and in many cases they may riddle a stick completely, so that it falls to pieces. The work of white ants, so destructive to all timber in warm climates, is of this character; and then we have the beetles, the larvæ of which bore into wood as soon as the same is dry enough to allow them to enter. The

decay of structural timber is, however, brought about most frequently by either bacteria or fungi. Bacteria are low plants which multiply with great rapidity by the method of fission or equal division. Fungi are low plants consisting of fine threads which start from a single spore, which, when brought under favorable conditions, sprouts or germinates. The mycelium, or aggregate of threads, grows in either living cells, in which case it attacks the protoplasmic contents, or in dead cells, in which case it attacks the cell walls.

The best conditions for growth of fungi and bacteria are an abundant food supply and a certain amount of heat and moisture. All require moisture. Where there is no water there will be no fungus or bacterial growth. Even the so-called "dry rot" fungi require a certain amount of moisture. Much of the rotting of timber could be prevented by heeding the simple fact that without water there will be no rot. At the same time, wood completely immersed in water will not decay, as the supply of oxygen necessary for the development of fungi is cut off.

Before proceeding to discuss the preservative treatment of wood, a few words in addition on the structure and chemical composition of the wood are desirable. Wood is composed of a series of closed tubes extending parallel to the long axis of a tree trunk. These tubes are firmly united laterally, and are so arranged as to fit into one another endwise, so as to form a splice.

The wood tubes differ very much in size and in their method of arrangement. In the hard woods one finds some very large tubes called ducts. These are entirely absent in the coniferous woods. As the cells grow older, they lose their original content of protoplasm, and become filled with air and various infiltrating substances, such as resins and gums. The fine original membrane of the cell and the groundwork of the thickening is composed of cellulose. This cellulose is infiltrated with various materials collectively known as lignin. This lignin may be dissolved out by the various fungi before referred to, leaving the cellulose skeleton, or *vice versâ*.

The infiltrating materials are deposited originally from solution, and the word "sap" is applied both to the solution and to the deposited substances, so that in air-dried wood we frequently speak of the fibre, the sap, and the air spaces as constituting the sum total of the wood. The following table, taken from Bulletin Number 9 of the United States Department of Agriculture, Division of Forestry, page 257, shows the

weight of 1 cubic foot of different kinds of air-dried wood and the space in cubic foot, or 1,728 cubic inches, of air-dried wood occupied respectively by fibre, sap, and air, assuming the specific gravity of fibre at 1.5.

	Weights of 1 Cubic Foot.				Space Occupied by Fibre, Sap, and Air.		
	Pounds.	Per cent. of water.	Weight of water.	Weight of fibre.	Fibre. Cubic inches.	Sap. Cubic inches.	Air. Cubic inches.
White oak . . .	53.3	16.0	8.5	44.8	830	161	662
Yellow pine . .	34.4	17.0	5.8	28.6	530	161	1,037
White pine . . .	26.1	17.0	4.4	21.6	400	125	1,203
White beech . .	45.2	18.5	8.4	36.8	681	233	814
White elm . . .	36.2	18.5	6.7	29.5	546	186	996
Sweet gum . . .	39.6	19.0	7.6	32.0	592	211	925
Yellow poplar .	33.0	19.5	6.4	26.6	493	177	1,058
Sycamore . . .	33.4	20.0	6.7	26.7	494	186	1,054

The earliest and most primitive method of preventing the decay of wood with which we are acquainted is the superficial charring of the wood, which, by coating it with a layer of porous charcoal, apparently keeps previously seasoned wood from being attacked by fungous or other vegetable growth. Pieces of charred piles and timbers used by the Romans in construction during the occupation of Britain, near the beginning of the Christian era, have been uncovered in recent times and found comparatively sound.

The application of this superficial carbonizing treatment on a large scale to ship timbers has been made in relatively modern times, both in England and in France, and experiments of this kind by M. Lapparent, naval constructor, are given in detail in Payen's "Chemie Industrielle," sixth edition (1878), 2, 74.

Two different lines of treatment have been proposed in modern times as tending to preserve wood from decay: the treatment by exclusion of air, and the impregnation of the wood by antiseptic solutions. Recalling what we said before as to the nature and causes of the decay of wood, it will be seen that the first class of methods was based upon erroneous conceptions. As the decay of wood is not simply

a slow oxidation, so the covering of the surface of the wood by an impermeable coating, which not only shuts out oxygen, but which shuts in nitrogenous constituents and some moisture, is not a proper solution of the problem of preventing decay. Nor will the so-called petrifying of the wood, or deposition of insoluble compounds in the superficial layers of the wood, completely prevent decay for the same reason.

With a proper understanding of the nature of the decay of wood we turn, therefore, to a consideration of the processes involving an impregnation with antiseptic solutions. Although a number of proposals had been made for impregnating wood by dipping it into solutions of metallic salts at times during the eighteenth century, and Sir H. Davy had called special attention to the preservative powers of corrosive sublimate, or mercuric chloride solution, in the first years of the nineteenth century, the first systematic process for the preservative treatment of wood dates from 1820, when Kyan applied to actual practice the process of using mercuric chloride, known since as "Kyanizing." Using a 2 per cent. solution, and immersing the timber in wooden tanks for periods of time ranging from eight to twelve days, excellent results were obtained. Of course, when hot solutions were used the time was shortened. The process has not achieved commercial success because of the expense of the chemical used and its very poisonous character.

Breant's process, announced in 1831, was for saturating in a closed cylinder under pressure, and was applied with different liquids. Thus he used copper sulphate, which was later used also by Boucherie in his imbibition process, and tar oils as well, which latter application was developed more fully in a commercial way by Bethell in England and Vohl in Germany, and became known as the creosote process. In 1837 Dr. Boucherie brought out in France his imbibition process for displacing the sap and natural fluids of the living or freshly cut wood by solutions of metallic preserving salts, like copper sulphate. The process attracted much attention, and, where it is applicable, there is no doubt that the wood is more efficiently saturated, and with less injury to its strength and structural value, than would be the case where it is impregnated under heavy pressure. The process was used very extensively in France, but most of the French railways abandoned it for tie-treating in 1878, and the last of the roads has now given it up for creosoting.

In 1858 Bethell brought out in England his method of impregnating in a closed cylinder under pressure with heavy tar creosote oils, which with some modification continues to the present day as the so-called

"creosote" impregnation process. In Bethell's process the wood, as, for example, railroad ties, was put in the cylinder, after some previous drying, and a vacuum having been created, the tar oil, at a temperature of about 100° F., was admitted, and the pressure increased to from 7 to 10 atmospheres, at which it was left from two to four hours. In some cases, with thick oils, the temperature was raised to about 150° F.

In the same year (1838) Burnett brought out the other process, viz., saturation with zinc chloride, which at the present divides with the creosoting treatment the practical work that is done in the way of impregnation. The zinc chloride impregnation is much cheaper than the creosote treatment, but the zinc chloride washes out in considerable degree from the treated wood on exposure to the weather, and its antiseptic value is at no time equal to that of the best creosote oil. Burnett at first merely laid the wood in the zinc chloride solutions; but, as the saturation was imperfect, later introduced the use of the closed cylinder and strong pressures. As the zinc chloride is used in aqueous solution, the opening up of the pores of the wood and softening of the sap contents by a preliminary steaming is always practiced. This is continued for about an hour at a temperature of about 235° F., or an extra steam pressure of 1.5 atmospheres. When the cylinder has cooled a vacuum is established, the zinc chloride solution is then admitted, and the pressure is raised to 7 or 8 atmospheres.

Of course numerous other substances of real or supposed antiseptic value have been proposed and tried, such as aluminum chloride, borax, ferrous sulphate, zinc sulphate, naphthalene, paraffine, solutions of resins, etc.; but with the abandonment of copper sulphate by the French railways the practical processes in use have narrowed down to either creosote or zinc chloride, or to mixtures of the two.

In a paper published in the *Transactions of the American Society of Civil Engineers*, in June, 1891, page 498, Octave Chanute, who has been connected with tie-treatment work in this country for a number of years, gives the results of his observations in Europe during the previous year, and from this a few points may be taken in passing. In England all antiseptics except tar oil have now been abandoned. The Bethell process is used, and the ties, after being well seasoned and cleared of sap, are treated without any previous steaming. The ties are mostly Baltic redwood from Russia, Sweden, and Norway, and the life of the tie thus treated is given as sixteen to twenty years.

In France copper sulphate has been finally given up, and either

creosote oil or a mixture of zinc chloride and creosote is used. "Burnettizing," or the use of zinc chloride alone, was tried, but abandoned because the chloride was found to leach out, especially in moist situations. In using creosote they inject more than the English do and get a longer life for the tie, amounting in some cases to from twenty-five to thirty years. The ties are dried, and go from the drying ovens directly into the treating cylinder while warm. The time required for treatment is two and one-half hours for oak and three hours for beech. The oak ties are then expected to last twenty-five years in the track and the beech ties thirty years, while untreated oak lasts but fifteen years.

In Germany, while the creosoting now predominates over zinc-chloride treatment, there are three processes in use:

(1) Impregnation with zinc chloride and tar oil.

(2) Creosoting, after seasoning and drying in ovens.

(3) Creosoting, after desiccation in hot tar oil.

The zinc-chloride creosoted ties, which are mostly pine, last from twelve to eighteen years, while the creosoted ties, which are mostly oak, are said to last from twenty-four to twenty-eight years.

In the United States work on tie-treating began prior to 1885, when a committee of the American Society of Civil Engineers made a report on the subject (*Transactions American Society of Civil Engineers*, 14, 247), and noted three modifications of the zinc-chloride process as being then in the experimental stage:

(1) The Wellhouse process. Zinc chloride containing some glue was injected and was followed by a treatment with tannin solution, the object being to form an insoluble combination of the glue and tannin which should hold the soluble zinc chloride in the wood and prevent its gradual leaching out.

(2) The Thilmany process, an injection of zinc or copper sulphate, followed by a solution of barium chloride, the intention being to form a soluble zinc or copper chloride and insoluble barium sulphate. This double decomposition did not take place within the wood, however, as was planned, and the process was abandoned.

(3) The zinc-gypsum process, an injection of zinc chloride and gypsum, both in solution, the idea being that when dried the gypsum would separate as an insoluble substance and prevent the dissolving out of the zinc chloride. The process was not a commercial success.

Earlier than these had been the straight zinc-chloride treatment,

or "Burnettizing," which was tried already in 1866; but it had been recognized here, as abroad, that the salt leached out. Walter W. Curtis, in a paper read May 17, 1899, and published in *Transactions of American Society of Civil Engineers*, **42**, 288, gives as an illustration of this the statement that some Burnettized ties taken up after a lapse of twelve years showed 0.146 per cent. by weight of zinc chloride in the wood, while when laid it had been 0.52 per cent. on the weight of the wood, showing a loss of over 70 per cent. of what was at best a very partial saturation.

Creosoting has also been tried, more particularly in the South and East, and has been relatively successful, the chief objection to its use as a process being its higher cost than the zinc-chloride treatment. Because of this it has been sought to combine the two, as was done in Germany. What is known as the Allardyce process is an impregnation, first with zinc chloride, and then, after partially removing the moisture from the wood, an injection of the creosote oil. It is, of course, cheaper than thorough creosoting, and it is believed that the creosoting will prevent the leaching of the zinc chloride. The weak point is generally the failure to eradicate thoroughly the moisture after the zinc-chloride treatment and before the creosoting, without which eradicating the creosote treatment is ineffectual. A creo-resinate process, using a mixture of 38 per cent. dead oil, 2 per cent. formaldehyde, and 40 per cent. melted resin, may also be mentioned as having been proposed a few years ago. The product has been used somewhat in building construction under the name of "vulcanized timber," but the process has not been used in tie preservation.

Let us turn now to the question of results. How complete is the impregnation effected by these processes, and how well is decay arrested and the strength of the wood preserved? In answer to this question I would call attention to the illustrations shown in the Bulletin Number 14 of the United States Department of Agriculture, Division of Forestry, by Hermann Von Schrenk, to which bulletin I am also indebted for much of the discussion on the nature of the decay of wood with which this paper was opened.

These illustrations show clearly that with the best German practice of creosote impregnation there is no complete impregnation of the timber treated; that the preservation does not extend to the interior of the wood; that dry rot may attack the part of the tie which the creosote has not reached, and that under some conditions actively growing fungus may attach itself to such a tie and cause disintegration.

The American practice, with both creosoting and burnettizing, is given in the Bulletin Number 9 of the United States Department of Agriculture, Division of Forestry (1894), on the authority of Mr. Kruttschmitt, general manager of the Southern Pacific Railway's preserving works, located at Houston, Texas. For creosoting the procedure is as follows:

"A vacuum of 22 to 24 inches is created (in the cylinder), requiring about ten minutes. Live steam is then turned in, destroying the vacuum and giving a temperature in the cylinders of about 125° F. This requires from fifteen to twenty minutes. The vacuum pump is again started, and a vacuum is created to open the pores of the wood well and to have the cylinders heated uniformly. This requires fifteen to twenty minutes. Live steam is again turned on, and the pressure raised to 30 pounds in about ten minutes, being held at this from six to eight hours, according to the size and kind of timber, care being taken to prevent the temperature from exceeding 250°. Steam is then blown off, requiring forty minutes. The vacuum pump is then again put into operation, and for the third time a vacuum of 24 to 26 inches is made, requiring about ninety minutes. While blowing off and obtaining this vacuum, and also during its continuance, the superheater is used to maintain a temperature of 225° on the timber. The third vacuum of 24 to 26 inches is maintained from four to six hours, after which the cylinders are filled with creosote oil at a temperature of about 170°. This requires about thirty-five to forty minutes.

"The pumps are then started, and the pressure is raised from 80 to 100 pounds per square inch and maintained from one to two hours, according to the kind and size of timber. The cylinders are then opened, after emptying them of the oil, and the train is pulled out and another charge made in forty to sixty minutes. The average time of treatment is from eighteen to twenty hours; the average absorption $1\frac{1}{4}$ gallons per cubic foot."

The zinc-chloride treatment, as carried out in the same works, is thus described:

"The zinc solution contains 1.7 per cent. of the chloride of zinc. This corresponds to $2\frac{1}{2}°$ on the scale of the Beaumé hydrometer.

"First, a vacuum of 22 to 24 inches is created, this requiring about ten minutes. Live steam is next turned in, destroying the vacuum and giving a temperature of about 125° in the cylinder. This takes fifteen to twenty minutes. The vacuum pump is again started and a second

vacuum created, requiring fifteen to twenty minutes. In this way the pores of the wood are well opened and the cylinder heated uniformly. Live steam is then again turned on and the pressure raised to 30 pounds, giving a temperature of from 240° to 250° F. This requires about forty minutes. The steam is held at 30 pounds pressure for from three and one-half to six hours, according to the kind and condition of timber. Steam is then blown off, taking about forty minutes. The vacuum pump is again started and a third vacuum of from 24 to 26 inches obtained, requiring about ninety minutes. After this the cylinder is filled with the zinc solution, taking about twenty-five minutes, and the pressure is then raised to from 80 to 100 pounds and held at this for from one to one and one-half hours, depending entirely upon the kind and the condition of the timber. The solution is then run off, taking about twenty minutes. The cylinder is next opened, the train pulled out, and another one placed in ready to start again in forty to sixty minutes from the time of opening the cylinders.

"The average time of treatment is from eleven to twelve hours. The cost of treatment of a tie 6 by 8 inches, 8 feet long, is from 9.5 cents to 12 cents. The average absorption per tie is four and one-half gallons."

The Wellhouse process, used quite extensively by some Western railroads, differs only from the straight zinc-chloride treatment in having some glue (two pounds of glue to 100 gallons of solution) added to the zinc-chloride solution and a supplemental treatment with a tannin solution, designed, as before explained, to coagulate the glue and form an insoluble, leather-like compound, which is to hold the zinc chloride in the wood.

It will be seen that under conditions of present practice a necessary part of the work is the preliminary steaming of the wood. This is admitted to be injurious to the wood. In Bulletin Number 9, before quoted, we find on page 263 the following reference to this: "But such long-continued steaming will soften the fibres, weaken their coherence, and reduce the strength of the timber. Experiments made in Hanover show that the ultimate strength of Burnettized wood was reduced by one-fourth to one-tenth, and its elastic limit by one-seventh. Some of this reduction was probably due to the action of the antiseptic used — chloride of zinc; but there can be little doubt that it was also partly due to steaming. Steaming has some other unfavorable features. A portion of the albumen, although coagulated, remains behind and par-

tially stops up the cells, hinders the free circulation of steam and sap, and ultimately the entrance of the antiseptic solution. The process, moreover, does not fully remove the viscid ingredients of the sap which, next to albumen, are most favorable to decay, while it deprives the wood completely of the essential oils and of tannic acid, which are to some extent preventives of decay."

When this prolonged steaming is followed by application of a vacuum we have the wood submitted to further injurious effects. The cell walls have been softened and the cell contents washed out, in part at least, by the steam, and the effect of the vacuum cannot but be to cause a collapse of the cellular structure thus impaired and a still further weakening of the wood when these successive influences have been exerted. This is now followed by the introduction of the impregnating liquid and the application of prolonged pressure, the effect of which, applied externally over the whole surface of the steamed and softened wood, is to compress the weakened tissue, and thereby to defeat the very intent of the application of pressure, viz., the entrance of the impregnating liquid into the cellular spaces. The consequence is that after an annular space, extending at most a few inches from the surface, becomes saturated, no further penetration is possible. This is clearly seen in the illustrations already cited. Why, then, is the steaming and application of vacuum practiced? Simply because without such softening and opening up of the exterior layers the existing cylinder treatment would accomplish almost nothing. The typical form of cylinder is shown in the accompanying illustration (Figure 1). It is from 62 to 84 inches in diameter and from 85 to 112 feet long, closed at one end, having a massive door at the other swinging either horizontally or lifted vertically. This door is fastened by a multi-locking system of bolts passing through lugs on the periphery of the cylinder. If this externally closed door leaks, no uniform pressure can be maintained. With any pressure above 150 pounds the cylinder leaks freely, and then the pressure pump must make it up, if the pressure is to be maintained, and, in speeding up, its reciprocating shocks delivered against wood, whose exterior surface has been softened by previous steaming, exerts a most damaging and disastrous effect. Therefore a lower pressure is used to avoid that compression of the wood, but a much longer time is required, and, as shown in the illustrations of Bulletin Number 14 before referred to, a partial impregnation is the best that can be accomplished.

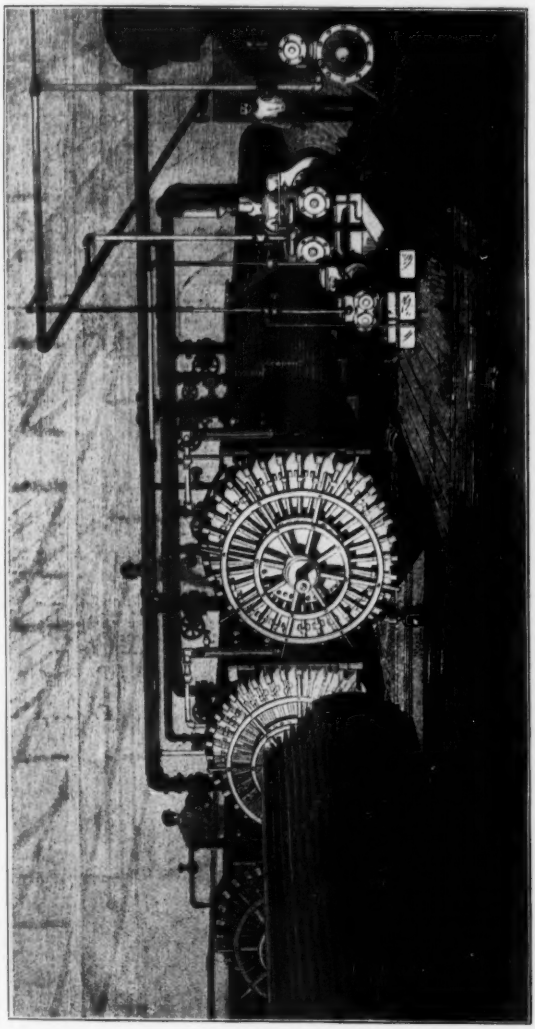

FIG. 1.—OLDER TYPE OF APPARATUS FOR THE SATURATION OF WOOD WITH FIRE-PROOFING MATERIAL.

I wish now to call attention to a radical departure from these methods of impregnation which, I believe, is to effect a revolution in the practice of tie-treating, as it has already done in the impregnation of wood for fire-proofing or making it fire-resistant to a degree beyond anything before accomplished.

In a paper which I read January 9, 1903, before the American Chemical Society and the Society of Chemical Industry in joint meeting at New York, and which was published in the *Journal of the Society of Chemical Industry* for February 28, 1903, I described the Ferrell apparatus for the saturation of wood with fire-proofing substances and exhibited the results of this process. The same inventor has invented and patented a tie-treating machine which, while embodying some of the essential mechanical features of the machine used for fire-proofing wood, is specially adapted to the tie problem. Both machines are shown in the accompanying illustrations (Figures 2 and 3). The large cylinder for general saturating work is made up of cast-steel flanged sections, $2\frac{1}{4}$ inches thickness of metal, with a special hydraulic joint at the flanges capable of enduring a hydraulic pressure of 1,000 pounds per square inch. At each end is a domed gate with a vertical hydraulic cylinder, superimposed, which operates a vertical gate-valve weighing 5 tons. The gate is provided with phosphor-bronze rings, as also the inner and outer guide surfaces; when the internal operating pressure comes upon the gate these ring surfaces coincide and the joint is perfect, whether with 10 pounds or 1,000 pounds pressure. The greater the pressure, the tighter the joint. It is exactly the reverse of the old externally applied gate, which leaks as the pressure increases. Furthermore, all possibility of communicated shock from the pressure pump is obviated by the interposition of a hydraulic accumulator loaded to the normal saturating pressure of each kind of wood, which has been determined by careful experiment once for all. No steaming and no vacuum are necessary, and the saturation is carried on at normal temperature without any injury to the structural strength of the wood, as has been verified by physical strength tests applied to the finished product.

For tie-treating, however, it has been found more advantageous to use a machine for saturating the ties individually, instead of collectively in numbers, and this operation is carried out with great speed and absolute thoroughness and uniformity. The machine, with respect to its hydraulic gate, is similar to the large universal machine. It has,

however, a gate at one end only, and is only a few inches longer than the tie. Each tie is packed so that the ends are wholly separated from the sides by the application to each end of a heavy rubber ring

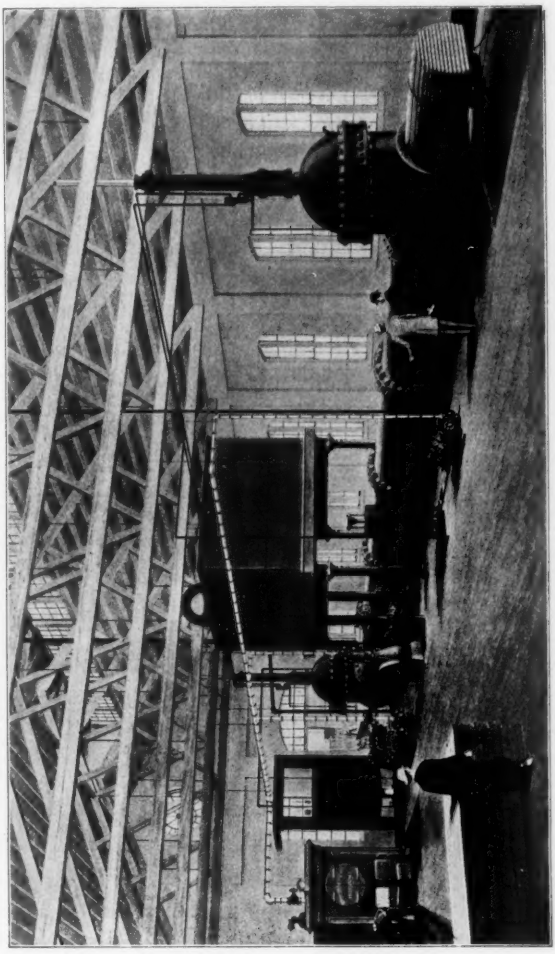

FIG. 2. — FERRELL APPARATUS FOR FIRE-PROOFING WOOD.

fitted in a cast-iron pad. The saturating chemical is applied at one end and a valve at the other end of the machine is left open, so that as the chemical enters under heavy accumulator pressure at the one end

it drives before it on the sap lines all the cellular air contents and sap water, which find their exit through the other end of the tie and out of the machine through the valve placed for that purpose. When the sap water, should there appear to be any, is wholly discharged, and the saturating chemical makes its appearance and no further expulsion exhibits itself, the exit valve of the machine is closed, while the pressure is still maintained, and the liquor thus forced in finds its way to the surface of the tie through the medullary rays, and then the saturation is complete. By this process it will be observed that the saturation with the chemical is effected from the centre of the tie to its surface, following the lines traversed by the sáp and the medullary rays to the surface, as opposed to the old method of attempting to force the liquor by a compression system from the surface to the centre, leaving no outlet whatever for the inclosed air of the cells and the sap water contained in the tie. The whole saturating process requires on an average not over nine minutes from the time the pressure is applied until the liquid comes to the surface of the wood on the sides.

It will be seen that this is in one sense a return to the Boucherie end method of injection, which was brought out in France over sixty years ago, but a little consideration will show that it is capable of results impossible by the Boucherie method. This latter depended for its efficiency on the fresh condition of the wood whereby the liquid sap could be displaced by the antiseptic solution with the aid of a very slight pressure, such as would be given by placing the reservoir of impregnating solution at a moderate height above the horizontally placed tree trunk or tree section. The new process not only takes advantage of the existence of sap channels, but follows that up by the forcing of the solution from centre to circumference by the aid of a steady, strong pressure. The completeness of the saturation is readily shown by sections cut from the interior of heavy ties. Of course it is obvious that any solution can be used with this form of apparatus, and can be put into the wood throughout its whole interior cellular area. We are thus allowed to choose the antiseptic entirely upon its merits as a preservative of woody tissue or because of other advantageous qualities.

The Ferrell Flameless Wood Company has found that the maximum of fire-resistant quality is given to wood by the use of aluminum sulphate without any accompanying injury to the structural strength of the wood or the production of any deleterious characters in the product. From these experiments and the experience of several years of

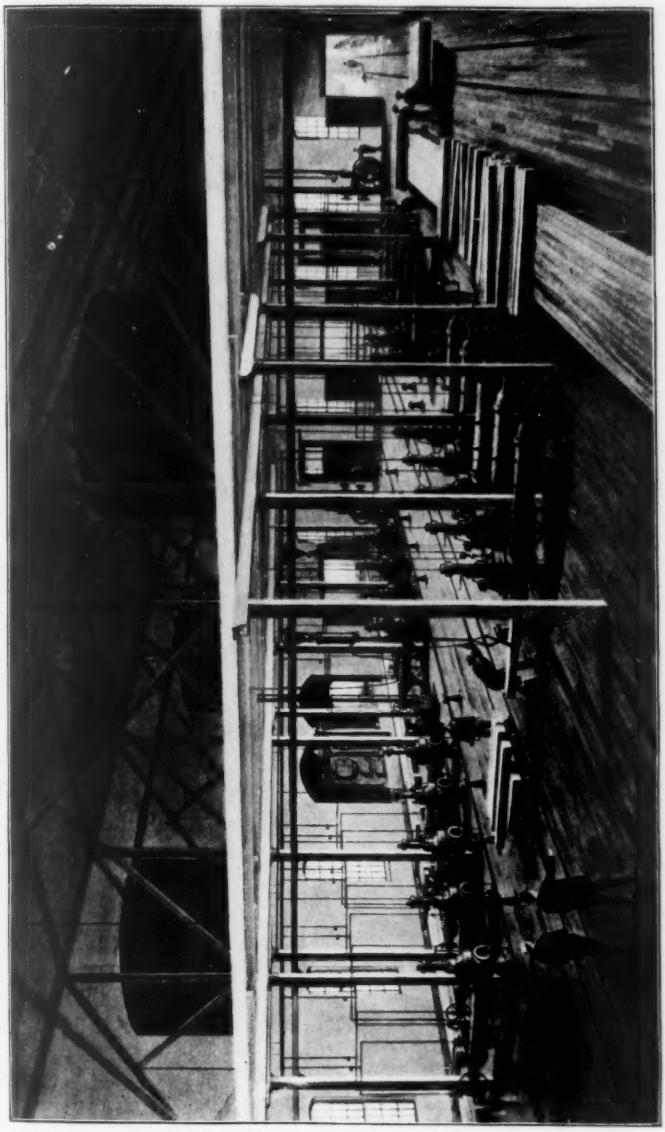

FIG. 3.—FERRELL APPARATUS FOR THE TREATMENT OF RAILROAD TIES.

study of the problem, the company has been led to believe that a mixture of aluminum sulphate with ferrous sulphate, made slightly basic by previous treatment with alkali, will give a cheap and strongly antiseptic solution that could be used to great advantage. The wood seems to harden without becoming brittle under this treatment, and is incapable of leaching after it has been allowed to dry properly. At all events, the thorough impregnation, now for the first time made possible, and the thorough displacement of the alterable elements of the wood will make tie treatment a sure and profitable means of greatly increasing the life of the wood used.

PHILADELPHIA, PENNSYLVANIA.

CONTRIBUTION TO OUR KNOWLEDGE OF WHITE LEAD AND OF ITS PROTECTING PROPERTIES.

By AUGUSTUS H. GILL and STANLEY A. FOSTER.

The statement is made in some of the books[1] that of all the common pigments white lead is the only one that combines with the oil in which it is ground. Save for repetition in other books the statement lacked confirmation, and it was with the object of corroborating this observation that this work was undertaken; and incidentally a study was made of the protective effects of the constituents of white lead.

White lead has the composition $2PbCO_3$, PbO_2H_2. This hydrate combines to a greater or less extent with the oil to form a soap or varnish in which the remaining constituent of the white lead is united as an emulsion. Solvents like gasolene or ether do not extract all the oily matter, consequently some must be in combination with the lead. This combination, or soap, is supposed to impart to the white lead the property — possessed by no other pigment to such a degree — of flowing readily and evenly from the brush.

To determine if a lead soap were formed, some white lead ground in linseed oil was treated in a Soxhlet extractor with gasolene until nothing more could be extracted; the mass was removed from the extractor and dissolved in hot concentrated hydrochloric acid. The mixture was filtered, and a dark-brown, curdy substance, resembling oxidized linseed oil, remained behind, containing some lead chloride, which was washed out with hot water. The residual substance was of a spongy nature, insoluble in alcohol, ether, and sodium hydrate; upon ignition an odor resembling tallow was given off. An attempt was made to saponify this compound, but without success.

Chrome yellow, $PbCrO_4$; red iron oxide, Fe_2O_3; "sublimed white lead," $PbSO_4$, and "French zinc," ZnO, were each extracted as above, and upon treating the residue with acid were completely dissolved. This would seem to indicate that there is a chemical action between

[1] Hurst, Painters' Colors, Oils, and Varnishes.

white lead and linseed oil which does not take place with other pigments. That this chemical action produces a lead soap is shown by the presence of the spongy mass, probably oxidized fatty acids, after treatment of the extracted portion with hot concentrated hydrochloric acid and hot water.

It is evident, therefore, that of the pigments, chrome yellow, "sublimed white lead," Venetian red, zinc white, and white lead, the latter is the only one which combines with the oil.

In order to determine just what part the lead soap plays in the properties of white lead as a paint, the following experiments were carried out. Some chemically pure lead hydrate, lead carbonate, and lead linoleate, which was presumably the lead soap formed, were separately prepared and ground in linseed oil; commercial white lead and "sublimed white lead" were used also.

The lead hydrate and carbonate were made by treating lead acetate with sodium hydrate or carbonate, removing the precipitated lead hydrate or carbonate, and drying with alcohol and ether. The lead linoleate was made by saponifying linoleic acid with lead hydrate. This linoleic acid was prepared according to the procedure outlined by Mr. H. A. Richardson in his thesis, Massachusetts Institute of Technology, 1887; 500 grams of linseed oil were saponified by heating with 150 grams of caustic soda and 700 cubic centimeters of alcohol on a water bath with a return condenser. The soap formed was dissolved in water and precipitated with 100 grams of calcium chloride. The calcium salts of the fatty acids thus formed were extracted with alcohol, dissolving the calcium linoleate, acidified with dilute hydrochloric acid, and the fatty acid was extracted with ether.

The five pigments, prepared as above, were applied to strips of sheet steel 6 x 2 inches and subjected to Loesner's steam test.

The method of procedure was as follows: each piece of steel, after having been thoroughly cleaned by an emery wheel and dried with alcohol, was given two coats of paint, each coat being allowed to dry at least four days. The pigments were ground in linseed oil immediately preceding their application to the steel. The lead hydrate upon drying turned red.

Loesner's steam test[1] consists in placing the painted pieces of steel over the aperture of a constant level water bath at the height of 5 centi-

[1] Chem. Rev. Fettu. Harz. Ind., pp. 4, 24, 329.

meters above the water, and supported upon strips of wood at each end to prevent abrasion. After fifteen hours' exposure to the ascending steam the paint was dried at 100°, softened with aniline, and removed with a soft brush. The strips were then dried with alcohol and examined for rust.

In each case the pigments were applied to three different pieces of steel for comparison. The following table gives the appearance of the paint after exposure to the steam test and drying at 100°:

BEHAVIOR OF WHITE LEAD AND ITS COMPONENTS WHEN SUBJECTED TO LOESNER'S STEAM TEST.

	I.	II.	III.
White lead	Surface good.	Surface good.	Surface good.
Lead carbonate . .	Slightly blistered and pitted.	Blistered and pitted.	Fair.
Lead hydrate . .	Blistered badly.	Bare surfaces in some places.	Blistered badly.
Lead linoleate . .	Quite bare of paint.	Pitted and bare in some places.	Bare in small places.
Lead sulphate . .	Slightly blistered.	Surface good.	Surface good.

APPEARANCE OF STEEL AFTER THE LOESNER TEST.

	I.	II.	III.
White lead	Very slight corrosion.	Very slight corrosion.	No corrosion.
Lead carbonate . .	Slight corrosion.	Slight corrosion.	No corrosion.
Lead hydrate . .	Much corrosion distributed evenly.	. . . . .	. . . . .
Lead linoleate . .	Much corrosion.	Much corrosion.	Much corrosion.
Lead sulphate . .	Slight corrosion.	Slight corrosion.	Slight corrosion.

From these experiments it would seem that white lead stood the test better than any of the other pigments, and that none of its constituents were equal to it in covering power. Lead linoleate would seem to be of no value except to increase the working quality of the paint, enabling it to flow better under the brush.

THE RECENT CONFLAGRATION IN BALTIMORE.

By C. L. NORTON.

(Read April 7, 1904.)

I VISITED Baltimore five days after the beginning of the fire and spent three days in looking over the field in a general way, interviewing eye-witnesses, and making a rather limited examination of the ruins largely from the streets. Ten days later I made a second visit of four days, spending the time almost wholly in studying the condition of the so-called fire-proof buildings, examining them all except the *Herald* building. The details of the fire and the general description of the condition of the district after the fire have been so thoroughly published as to call for no further repetition here, and it is my purpose to call attention only to the more technical lessons to be learned from this conflagration.

A study of the conditions prevailing in the portions of Baltimore which were recently destroyed by fire, and of the structures in this district after the fire, leads to two general lines of suggestion for future safety of similar districts in cities now built or to be built.

The first thought that occurs to one in looking over the situation is the similarity of conditions prevailing in almost all large cities in the matter of lack of preventive measures for retarding the spread of fire from building to building — the lack of protection against exposure hazard. The second thought brought home by the towering remains of the tall steel-frame buildings is the failure of the word "fire-proof" to give any proof of its right to exist as applied to such buildings.

The danger of spread of fire through the whole of such a district needed no new emphasis. Boston, Chicago, Paterson, and other cities had shown that none of the preventive measures in use in such cities would avail against a fire started during a gale of wind in a district composed largely of buildings of inferior construction. What happened in Baltimore is likely to happen in New York or Boston, if once a fire

gets well under way. The danger is not so great, perhaps, in some other cities as it was in Baltimore, but its presence must be admitted.

The measures to be adopted to prevent the possible spread of conflagration in cities have been enumerated by abler pens than mine, but I will venture upon a few suggestions: First, remove from these crowded cities the greatest cause of quick spread of fire, in the shape of explosive material. It has been said that explosions of chemicals occurred in the early part of this fire; but whether or not this was really the case, or whether there was a series of so-called hot-air explosions from the products of distillation, it seems clear that something in the nature of an explosion scattered the fire.

As is well known, the products of distillation in a slow fire smoldering for some time before becoming rapid in its spread may, when mixed with air, become explosive. The opening of a door or breaking of a window may cause a draft that leads the flames toward the smoky mixture and starts the explosion, known to the firemen as a "hot-air" explosion. Sprinklers and ventilation and stops in vertical openings tend to minimize this danger.

Stringent laws against storing explosive merchandise and care in installing ventilation systems, thermostat systems, and sprinklers will tend to minimize the danger of early spread of fire by explosion.

Unless violently scattered as by an explosion, fire spreads through such a district by the carrying of sparks, by direct contact of flame, and by radiation across open spaces. Protection against all these dangers is to be sought by means of non-inflammable roof materials, shutters, wired glass, in metal or metal-covered frames for all openings, and roof hydrants.

Fire has apparently in this case found its way from building to building through doors and windows and through roofs which offered but slight resistance. There were buildings in this district equipped with tinned and sheet-iron shutters and some with other protective devices, but few or none withstood against the enormous volume of flame and hot gases coming from the majority of partially protected or unprotected risks. There is nothing new in this, but it is a condition so common and so dangerous as to bear repeated references.

I am satisfied that with roof hydrants having a good supply of water, and the universal use of wired glass and tinned shutters and metal-covered sash in this district, the Baltimore fire of 1904 had been relatively a small conflagration. And, further, the systematic use of

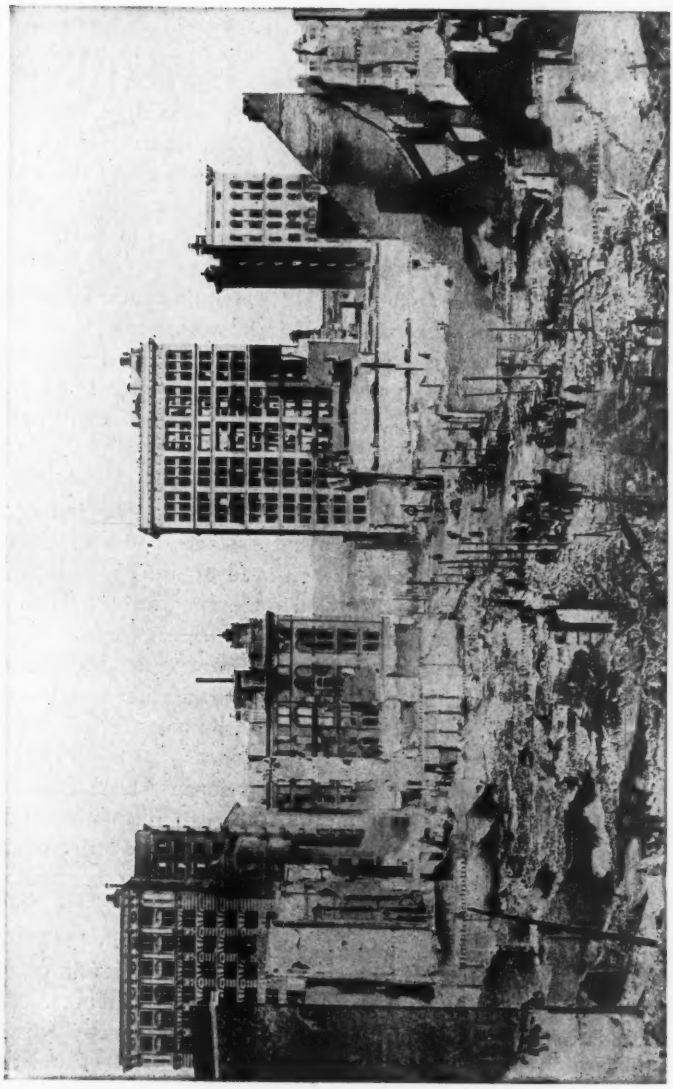

FIG. 1.—GENERAL VIEW OF THE GROUP OF "FIRE-PROOF" BUILDINGS A WEEK AFTER THE FIRE.

these three preventive appliances and sprinkler systems in other cities where they are not in use would greatly decrease the conflagration risk.

The second and more interesting line of suggestion comes from a minute study of the condition of some seventeen so-called "fire-proof" buildings in the burned district. Some of these are untouched. Some are ruined. Some are sadly damaged. Let us see why their conditions are so different and why some fared so badly.

It is apparent at once that some of the buildings are intact in large part because of their having been less vigorously attacked by the fire than were the others and for no other apparent reason.

These buildings being low, surrounded by taller neighbors, or situated on street corners, seem to have been actually jumped over by the wave of combustion. There is ample evidence that the outside of these buildings did not rise in temperature to the igniting point of wood or paint. On some of them not even the skylights are broken, and an almost incredibly small amount of damage was done to their exterior. In most cases the buildings may be said to have been without a severe fire trial.

A second group of fire-resisting buildings includes those which have been well described by the word "monumental." The court house and city hall offer examples of this type, being heavy stone buildings, with comparatively few window openings. Offering a small area for the entrance of fire and a non-inflammable exterior, these buildings withstood great heat, with no damage except from the spalling of the stone and charring of window frames. It should not be assumed, however, that the fire was driven toward these buildings with such fury as that which it expended on some of the steel-frame buildings, as accounts indicate that a change in the wind diverted the fire from them at the most opportune time. On the whole, these monumental buildings demonstrate the effectiveness of a minimum window area in reducing the danger of ignition, rather than anything else. They further call attention to the frailty of stone. The modern steel-frame construction, popularly called "fire-proof," was exemplified by some half-score of buildings in the edge and centre of the burned area. These buildings furnish material for much study, and, from their defects as here demonstrated, I have no doubt that we may learn much that will go far to prevent even the partial destruction of such buildings built in the future.

FIG. 2.—INTERIOR OF EQUITABLE BUILDING, STREET FLOOR; SHOWS FAILURE OF FLOORS AND FALL OF SAFES.

The general condition of the steelwork itself is apparently good, except in a few instances. Neither the fire nor corrosion preceding the fire has sensibly affected it, if we may judge from its appearance. The "fire-proof" buildings of steel-frame construction show in general failures along the same lines. Where the walls are substantial and of good red brick, they stood the test fairly well. There was some spalling and in some cases a crumbling, but good red bricks seem to have lived up to their earlier reputation. Where brickwork of a lighter color, ornamented with terra cotta, was used, considerable more damage was noticeable, especially after the slight snowstorms of the week following the fire. Stone trimmings, almost universal on the lower fronts, demonstrated the unfitness of that material beyond all question. Granite, marble, sandstone, and limestone all fared about alike, even when, as near as can be ascertained, very little or no water was thrown upon them. In general all outside wall material suffered, but brick much less than the rest.

It has already been said that the steel frames themselves appeared in good condition. Exceptions to this may be found in the Equitable Building and in the upper stories of some of the others. None of these frames, however, collapsed and none is likely to do so, though some posts and beams were bent or crushed and some will need to be replaced in nearly every one of the steel-frame buildings. The light steel frame of the somewhat older Equitable Building is seriously injured and a considerable amount of reconstruction is needed here. Posts are bent and sagged and beams are badly deflected. It is probable that this light frame was subjected to a great strain from the falling of the safes after the plank top floor burned through, the arches of terra cotta not being strong enough to carry their weight.

The steel frames will need careful examination to note possible distortion or weakening. In general the frames are not injured by more than 10 per cent., and in some cases by a much less amount, though in the Equitable Building the loss to the steel would seem to be between 50 per cent. and 75 per cent., or even more.

The posts and beams in about all these buildings were covered either with terra cotta or with "lime-teil," a material whose composition appears to be in the nature of a plaster and cinder mixture. Generally the covering served its protective purpose well, but was itself destroyed or badly damaged. A very large percentage of the terra cotta and lime-teil block must be replaced, and it is the general,

FIG. 3.—A WINDOW IN THE UPPER STORY OF THE EQUITABLE BUILDING.

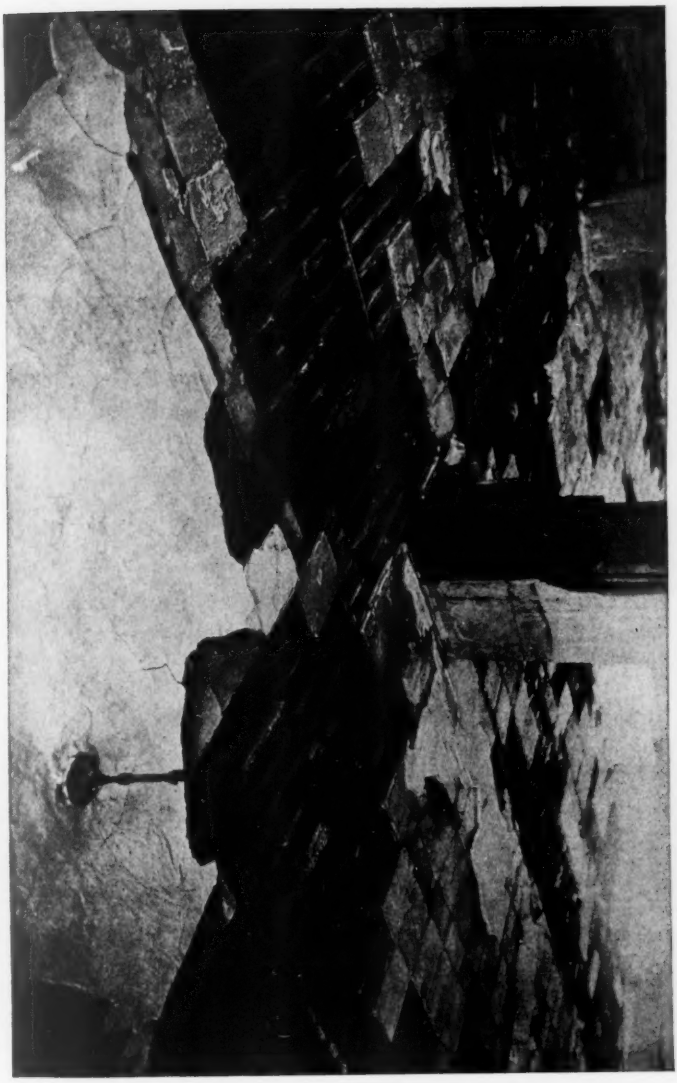

FIG. 4.—SHOWS THE CONDITION OF A LARGE PART OF THE TERRA COTTA FLOOR ARCHES IN THE CONTINENTAL TRUST COMPANY'S BUILDING.

almost universal, condition that the beam covering of the flanges is gone. The loss of terra cotta beam and post coverings was at least 75 per cent.

The partitions of terra cotta and lime-teil are very largely destroyed and the unfitness of these materials for this purpose seems clear. Many partitions have fallen and more are in such condition that they must be replaced. Much of the lime-teil is softened and the terra cotta is cracked or broken and the bond between blocks is loosened. If metal lath partitions were in existence to any great extent, they failed as well, for few were in evidence in good order.

The floor arches of many different spans and of different details of construction, but in the main of terra cotta or lime-teil, show much the same sort of distress as the partitions. The bond between the tiles is broken, quite generally, and the tiles themselves are cracked and broken in great numbers. The lower face, or soffit, of the tiles has split off over large areas, and 50 per cent. or 60 per cent. of the terra cotta floor construction will, I fear, need to be replaced or reënforced.

Where concrete floor arches and concrete steel construction received the full force of the fire it appears to have stood well, distinctly better than the terra cotta.

The reasons, I believe, are these: First, because the concrete and steel expand at sensibly the same rate, and hence when heated do not subject one another to stress, but terra cotta usually expands about twice as fast with increase in temperature as steel, and hence the partitions and floor arches soon become too large to be contained by the steel members which under ordinary temperature properly enclose them. Under this condition the partition must buckle and the segmental arches must lift and break the bonds, crushing at the same time the lower surface member of the tiles. Especially in the Calvert Building I found evidence which leads me to believe that not an excessive temperature, but the differential expansion under a moderate high temperature of the terra cotta of the top and bottom members and of the enclosing steel is responsible for the general failure of the terra cotta partitions, beam covering, and floor arches. Secondly, Mr. Gray suggests that there is a similar unequal expansion of the top and bottom faces of the separate tiles, which causes the lower faces to expand and shear off. Evidences of this were found everywhere.

Further examination of the expansion phenomena points to them as the main source of distress to the whole beam and post covering, floor,

FIG. 5.—A ROOM IN THE CALVERT BUILDING SHOWING FAILURE OF PARTITIONS.

arches, and partitions. Most of the fallen terra cotta partitions and the floor blocks were still hard and had a clear ring when struck, though cracked and broken. There was no evidence of any such temperature as that at which the terra cotta had been baked originally, and the material of the blocks could not have been altered chemically. It will be readily understood that the thin-walled hollow tiles would become heated upon one side much more quickly than would the equivalent area of a solid partition of brick or concrete. Terra cotta, cinder concrete, and stone concrete all have about the same heat-absorbing power, or specific heat, and hence the heavier and more solid the partition or floor, in other words, the more material there is in it, the slower will be its rise in temperature and its subsequent expansion.

I question whether any floor containing so little material on its outer faces as did these hollow blocks could remain sufficiently cool in this fire to avoid serious injury from expansion.

The minor details of the structure and finish fared badly. Wood is not in evidence except in secluded corners. Marble, slate, plaster, and in fact all similar surfacing material suffered to the point of destruction. The cast-iron stair frames and rails stood remarkably well in most instances.

The building of United States Fidelity and Guarantee Company is an interesting example of reënforced concrete in the district. As near as I could ascertain, it was subjected to a severe fire and I found evidence of temperatures up to the softening point of cast iron. The condition of the lower part of the structure and apparently of the whole structure showed the great fire-resisting powers of this type of building. It is of especial interest in that the Insurance Engineering Experiment Station made a preliminary test on an arch of this same type and of almost this exact thickness and span and weight of metal, which failed because of the slender 6-inch posts, and not through the failure of the floor, at the end of three hours and forty minutes' exposure to a 1,700° to 2,000° F. fire.

Further, in the International Trust Company Building a small paper room, having a Hennibique floor and ceiling, was so intensely heated that at the end of three days the lumps of cast iron which had earlier been a copying press and an embossing stamp were still red-hot, and yet neither floor nor ceiling show signs of distress. This is the more remarkable in that the walls of the adjoining building fell through the skylight upon the Hennibique floor. There were in the Commercial

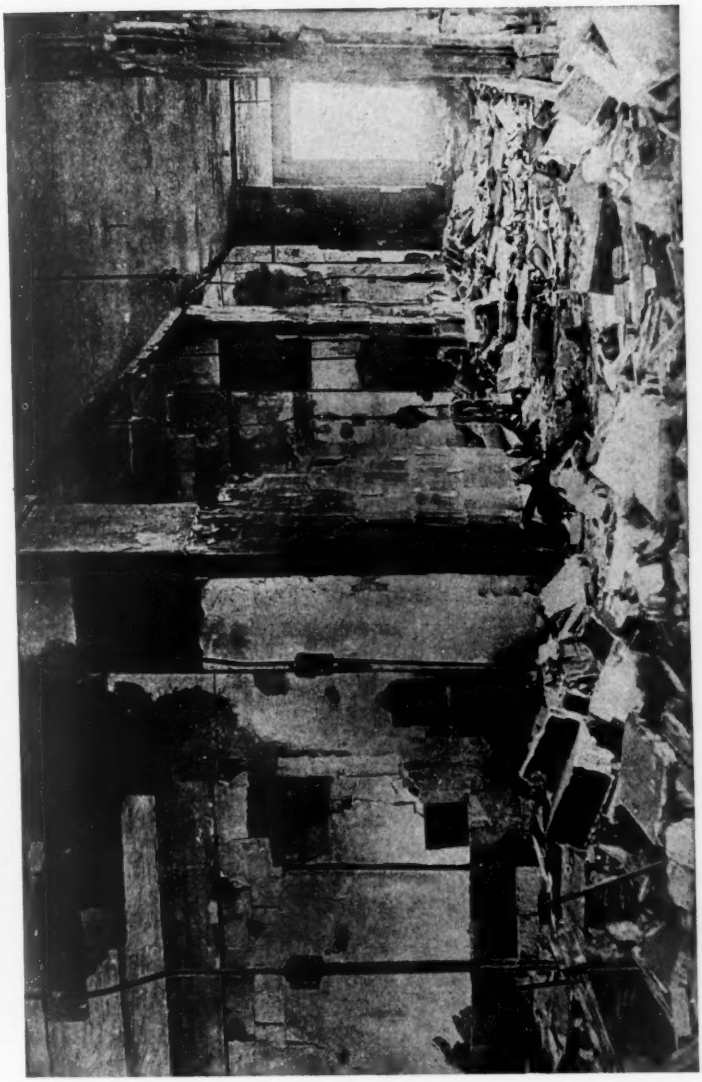

FIG. 6.—VIEW IN THE CONTINENTAL TRUST BUILDING.

and Farmers National Bank and in the National Bank of Commerce concrete floors which stood the fire test well.

The general condition of the fire-proof building is such as to indicate to my mind the unfitness of terra cotta for beam and post covering and floor construction as here used when compared with concrete or brick-work. Second, there is no evidence that the tall steel building was subjected to an unusually severe test. While it must be admitted that not enough concrete received the full effect of the fire to make the test a perfectly complete one, when I add to this the experience of several years in examining the action of fire upon concrete, I am convinced that had the floors of the Continental Trust or the Calvert Building been of any one of the better class of concrete types, and had the beams and posts been encased in 4-inch coatings of sound concrete, then renewal would have required little but plastering.

Little difference in the action of the fire on stone concrete and cinder concrete could be noted, and, as I have earlier pointed out, the burning of the bits of coal in poor cinder concrete is often balanced by the splitting of the stones in the stone concrete. I never have been able to see that in the long run either stood fire better or worse than the other. However, owing to its density, the stone concrete takes longer to heat through. When brick or terra cotta are heated no chemical action occurs; but when concrete is carried up to about 1,000° F., its surface becomes decomposed, dehydration occurs, and water is driven off. This process takes a relatively great amount of heat. It would take about as much heat to drive the water out of this outer quarter-inch of the concrete partition as it would to raise that quarter-inch to 1,000° F. Now a second action begins. After dehydration the concrete is much improved as a non-conductor, and yet through this layer of non-conducting material must pass all the heat to dehydrate and raise the temperature of the layers below, a process which cannot proceed with great speed.

Much has been said about the uncertainty of concrete. The value of concrete in theory is often admitted by those who consider it unwise to use it because of the difficulty of getting the materials properly proportioned, mixed, and placed in position. I have never been able to see the force of this. It is quite as easy to lay sound concrete as it is to put somewhat irregular and confessedly brittle blocks of terra cotta into place with proper bonding. The main difference seems to be that poor concrete reveals its weakness when it falls on "pulling

FIG. 7.—VIEW IN THE LIGHT WELL ON THE REAR OF THE CONTINENTAL TRUST BUILDING.

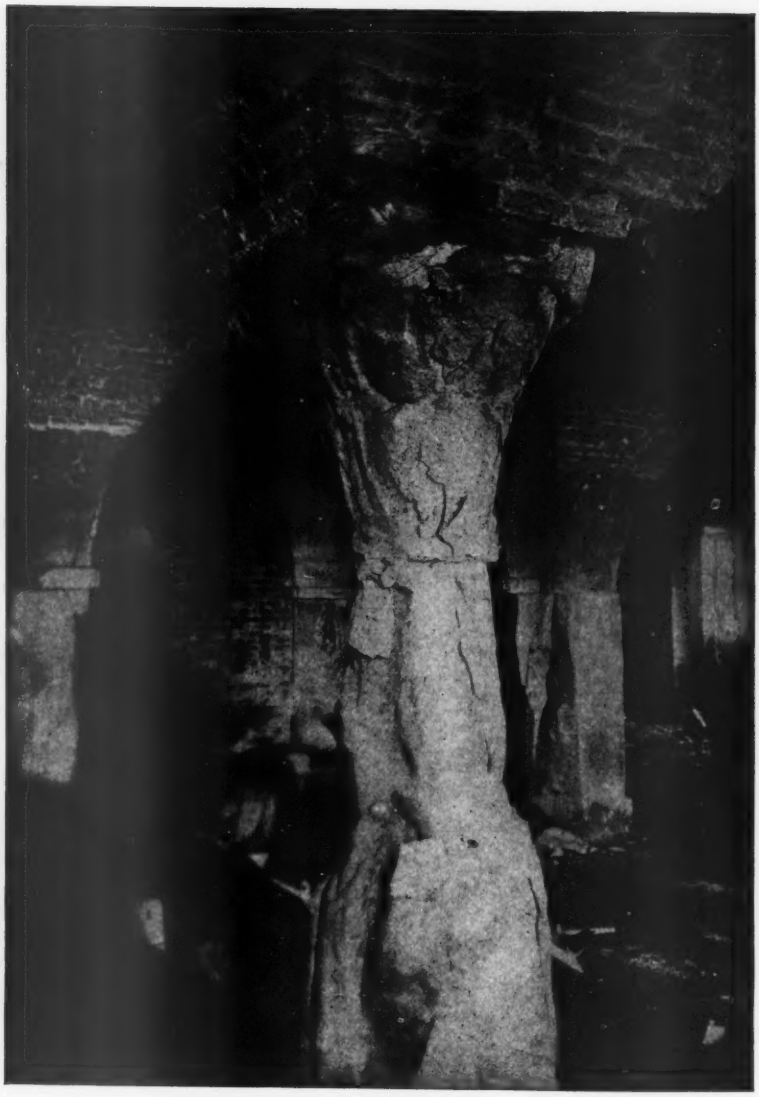

FIG. 8.—THIRTY-SIX-INCH STONE (GRANITE) COLUMN IN U. S. STOREHOUSE. BADLY SPALLED BY HEAT.

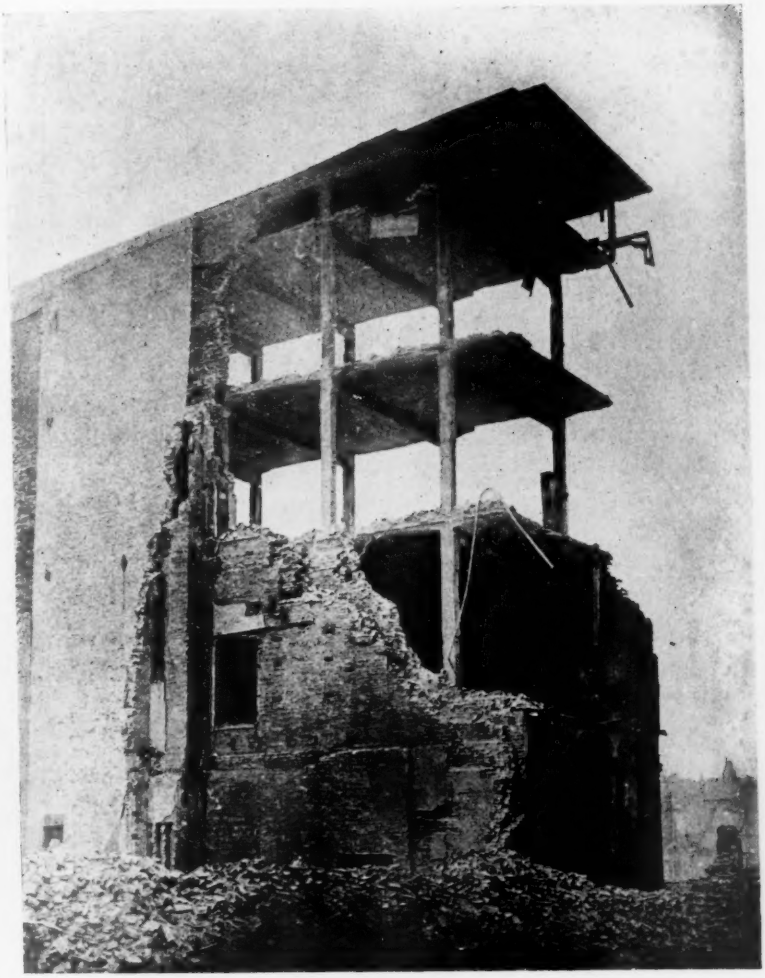

FIG. 9.—FERRO-CONCRETE STRUCTURE STANDING AFTER THE FIRE.

the centres," while terra cotta is likely to be strong enough to hold itself in position even when it can do little more. Further, a prolonged search revealed only occasional evidence of temperatures as high as 2,400° F., and no instance could be found of real fusion of terra cotta or brick in them. Occasional evidences of temperature of 2,200° F. were found, but in general there was ample evidence that the temperature of the fire in these buildings had never in most places risen above 1,700° F. This is likely to happen in almost any office building where little care is taken as to the nature of its contents, and must be provided for if these buildings are to be proof against the combustion of their own contents.

It seems apparent that, with care, steel frame buildings can be so constructed as to stand the destruction of their contents without injury to the steel and probably without danger to the protecting material or floor arches; that, with shutters and wired glass, the burning of more combustible neighbors may be expected to cause little permanent injury to the structure proper; and that a district composed wholly of such buildings would be reasonably immune from danger of conflagration.

A DESCRIPTIVE CATALOGUE OF THE BUILDING STONES OF BOSTON AND VICINITY.

By W. O. CROSBY and G. F. LOUGHLIN.[1]

Introduction.

The character, the sources, and, above all, the behavior in use and the durability of the building stones of a large city should be matters of interest to architects and builders, to students of economic geology, and to the general public. For more than two hundred and fifty years stones of various kinds have been used in Boston for building purposes; and more than one hundred varieties are represented in buildings standing in this city today.

This wealth of material affords an excellent opportunity for a comparative study with respect to both durability and adaptability, but heretofore no systematic inquiry along these lines has been attempted. Some twenty years ago Professor A. A. Julien,[2] of Columbia University, investigated the decay of the building stones of New York City, and we have thought to make a somewhat similar study of the building stones of Boston.

The scope of this work includes for each stone: first, its identification, geologic and geographic; second, a brief description, with the results of such analyses and tests as may be available; third, a list of the more important structures in which it has been used, with, as a rule, the date of erection of each and a general indication of the way in which the stone has been used, including architectural position and kind of finish; fourth, the general behavior of the stone in use, with special reference to its failure where overloaded and the extent and mode of its decay or alteration under prolonged exposure to the weather;

[1] This paper embodies the principal results of an investigation of the building stones of Boston made by Mr. Loughlin, under my supervision, and submitted in May, 1903, as a thesis for graduation in the Department of Geology of the Massachusetts Institute of Technology. The observations recorded here should, therefore, be credited chiefly to Mr. Loughlin. — *W. O. Crosby.*

[2] Transactions New York Academy of Science, 1883, pp. 67–138.

and fifth, a general estimate of the value and adaptation of the stone, and an explanation of the variations in esteem which many stones have experienced, leading to fluctuations in extent or mode of use

Conglomerate.

Roxbury Puddingstone. — Because of their prevailingly coarse, irregular, and friable texture, the conglomerate rocks are, in general, of little interest or value as building stones; the local conglomerate, known familiarly as the Roxbury puddingstone, is, however, an important exception, and it is entitled to rank as one of the chief building stones of Boston.

Occurrence. — This stone represents one of the principal rock formations of the Boston Basin, and is supposed to be of Carboniferous age. Although widespread and abundant both west and south of Boston, it is favorably developed for quarrying in but few localities; and the principal quarries, or those supplying the major part of the material finding important use, are those on the north side of Parker Hill in Roxbury. It may be noted, however, that the ledges in Brighton and Newton have supplied most of the puddingstone used in those districts and in Cambridge. Many quarries, including some of considerable extent, have been worked chiefly or exclusively for road metal; and where architectural stone has been the primary consideration, the waste rock has usually been crushed for use on roads.

Description. — The Roxbury puddingstone is normally a firmly cemented aggregate of well-rounded or water-worn pebbles of Cambrian quartzite, and of granite and felsite of many different varieties. The paste is largely argillaceous and well-lithified, and the pebbles range in size up to cobblestones and even bowlders, the lower beds of the conglomerate being, in general, much coarser and more irregular in texture than the upper beds. But little puddingstone is used containing pebbles more than two inches in diameter, and, in general, its architectural value varies inversely as the average size of the pebbles. Owing to its coarse and pebbly texture, it cannot be satisfactorily dressed, and it would, therefore, be almost valueless as a building stone but for its remarkably regular and perfect joint structure. The joints, or seams, are plane, cutting the hardest pebbles without deviation; and the joint faces are, in general, well-oxidized or iron-stained, developing a warm and permanent brown color, richly mottled in many blending tints. This is a

typical *seam-face* building stone; and in all first-class work the rusty joint surface forms the face of the stone, which cannot be successfully dressed or carved, but must be used with nature's finish, and which is thus practically limited in use to plain surfaces or ashlar work. On account of this limitation it is necessary, in all good work, that some other stone, as granite or freestone, should be employed for the corners, the dressing of apertures, and the trimmings generally.

The puddingstone does not adapt itself readily to compressive and other tests on account of the difficulty or practical impossibility of dressing it to the required forms, and we have obtained a record of but one test. This was made at the Watertown Arsenal in June, 1886, for the Roxbury Stone Company. The specimen used was a hammer-dressed cube approximately 5.5 inches each way. This was faced with plaster of Paris, and its crushing load was found to be 17,360 pounds per square inch, or equal to that of a good grade of granite. The weight of this cube before crushing was equivalent to 174.5 pounds to the cubic foot, a high result for a clastic rock of decidedly siliceous character, indicating that the paste of the conglomerate is essentially nonporous, and suggesting that its consolidation, although due primarily to the lithification, or hardening of the argillaceous or clayey constituent, may be attributed in good part also to secondary silica, thus explaining the weight, the strength, and the durability of the puddingstone.

Examples. — Only the more important public and semi-public puddingstone structures are enumerated, including, in chronological order:

1833. St. James Episcopal Church, St. James St., Roxbury. Built of puddingstone in rough and irregular blocks, often without seam-face, and practically no trimmings, except a few flagstone copings and sills.

1852. St. Paul Episcopal Church, St. Paul St. and Aspinwall Ave., Brookline. Trimmed with Bay of Fundy freestone.

1854–65. Burkhardt Brewery, Parker and Station Sts., Roxbury. Puddingstone from the Parker Hill quarries, trimmed with Quincy granite. The dwelling house (1864) on the south side of Station St., opposite the brewery, is of the same materials.

1859–60. Highland Hall, Warren St. and Walnut Ave., Roxbury. Seam-face puddingstone from May's Woods quarry, Roxbury, trimmed with Quincy granite.

1860 Christ Church (Sears Chapel), Colchester and Chapel Sts., Brookline. Trimmed with Bay of Fundy freestone.

1860–61. Tremont St. Methodist Episcopal Church, Tremont and West Concord Sts. Puddingstone mostly in small, flat blocks, trimmed with Bay of Fundy freestone.

1861. Church of the New Jerusalem, High and Allerton Sts., Brookline. Trimmed with Bay of Fundy freestone.

1865. Central Congregational Church, Berkeley and Newbury Sts. Trimmed with New Jersey brownstone.

1865–66. Colby Hall, Newton Theological School, Newton. Puddingstone from Newton ledges, trimmed with Bay of Fundy freestone.

1865–84. Forest Hills Cemetery: gateway and lodges (1865) and chapel (1884) trimmed with freestone, and bell tower (1876) trimmed with Quincy granite.

1867. First Church in Boston (Unitarian), Berkeley and Marlboro Sts. Trimmed with Longmeadow brownstone and Bay of Fundy freestone, with five columns of pink granite from Jonesboro, Maine.

1868. St. John's Memorial Church (Episcopal), Brattle and Mason Sts., Cambridge. Trimmed with Bay of Fundy freestone.

1868. Church of Our Saviour (Episcopal), Carlton and Monmouth Sts., Brookline. Trimmed with micaceous granite. Parish House (1880), Rectory (1885).

1869–70. First Church, Elm and Newbern Sts., Jamaica Plain. Trimmed with coarse, pink Braintree granite.

1869–70. Bussey Institute, South St., Forest Hills. Trimmed with Bay of Fundy freestone and brownstone.

1869–70. Newton Public Library, Centre St. Small blocks of puddingstone from Newton Centre, trimmed with Hallowell granite.

1870. Union Congregational Church, Columbus Ave. and West Newton and Rutland Sts. Trimmed with Bay of Fundy freestone.

1870–75. Cathedral of the Holy Cross, Washington and Malden Sts. Trimmed with Cape Ann hornblendic granite.

1872. Second Universalist Church, Columbus Ave. and Clarendon Sts. Trimmed with Bay of Fundy freestone and brownstone.

1872. Walnut Ave. Congregational Church, Walnut Ave. and Dale St., Roxbury. Trimmed with Bay of Fundy freestone.

1872–73. St. Columbkille Catholic Church, Market and Arlington Sts., Brighton. Puddingstone in small rectangular blocks (seam-face) from Brighton ledges, trimmed with Bay of Fundy freestone and Connecticut brownstone.

1872–73. Grace Episcopal Church, Eldredge and Church Sts., Newton. Small, seam-face Brighton puddingstone, trimmed with Bay of Fundy freestone and brownstone.

1872–73. First Universalist Church, Washington Park, near Walnut St., Newtonville. Small and irregular blocks of Newton puddingstone and sandstone of various colors and only in part seam-face, trimmed with Bay of Fundy freestone and Longmeadow brownstone and red brick.

1872–77. Holy Trinity Catholic Church, Shawmut Ave. and Cobb St. Trimmed with light granite.

1872–93. Episcopal Theological School, Brattle St., Cambridge. Built of conglomerate, sandstone, and slate from the Brighton ledges, trimmed with brick, with freestone caps, sills, and keystones. Winthrop Hall (1893) is similar, but trimmed with Longmeadow brownstone, with a water table of Hudson River flagstone.

1873. New Old South Church and Parsonage (Congregational), Boylston and Dartmouth Sts. Church trimmed with Ohio freestone and Portland brownstone. Parsonage trimmed with Bay of Fundy freestone.

1873. St. Peter's Catholic Church, Bowdoin St. and Eaton Sq., Dorchester. Trimmed with micaceous granite.

1874. Roxbury Church of the New Jerusalem, St. James and Regent Sts., Roxbury. Trimmed with Bay of Fundy freestone and dark green massive chlorite schist from Rowe, Massachusetts.

1875. Immanuel Congregational Church, Moreland and Copeland Sts., Roxbury. Trimmed with Bay of Fundy freestone.

1876–78. Church of Our Lady of Perpetual Help (Catholic), Tremont St., Roxbury. Trimmed with Cape Ann granite.

1881, '98. Emmanuel Episcopal Church, Newbury St. Trimmed with Bay of Fundy freestone.

1882. First Baptist Church, Clarendon St. and Commonwealth Ave. Trimmed with brownstone and Ohio freestone.

1882. St. John's Episcopal Church, Roanoke Ave. and Revere St., Jamaica Plain. Trimmed with Ohio freestone.

1882–84. St. John's Seminary, Lake St., Brighton. Irregular and usually small blocks of Brighton puddingstone, trimmed with Ohio freestone, Concord granite (steps and water table), St. George red granite (two polished columns), and brick.

1886. Church of the Holy Spirit (Episcopal), River St., Mattapan. Rough blocks of puddingstone with but few seam-faces and no trimmings save wood and concrete.

1889. All Souls Unitarian Church, Warren St. and Elm Hill Ave., Roxbury. Built of irregular blocks of puddingstone, trimmed with rock-faced Quincy granite.

1891. St. Mark's Methodist Episcopal Church, Park and Vernon Sts., Brookline. Trimmed with Bay of Fundy freestone.

1891. Roxbury Presbyterian Church, corner Warren and Woodbine Sts. Trimmed with Braintree pink granite.

1891–92. Mt. Vernon Congregational Church, Beacon St. and Massachusetts Ave. Trimmed with hornblendic granite from Deer Isle, Maine, and Ohio freestone.

1891–92. First Parish Unitarian Church, Walnut and Warren Sts., Brookline. Trimmed with Ohio freestone.

1893. Brooks Memorial Chapel, adjoining Grace Church, Eldredge and Church Sts., Newton. Brighton puddingstone and slate, trimmed with brownstone and Ohio freestone.

1893–93. Church of the New Jerusalem, Highland Ave., near Walnut St., Newtonville. Irregular blocks of seam-face Brighton puddingstone, trimmed with Ohio freestone.

1895. Townsend Memorial Library and Chapel, adjoining Grace Church, Newton. Puddingstone and ripple-marked sandstone and tuff of various colors, all from Warren St., Brighton, trimmed with Ohio freestone.

1898–99. Methodist Episcopal Church, Langley Road and Centre St., Newton Centre. Puddingstone in rough and irregular blocks, but chiefly seam-face, from local ledges, and including much sandstone and slate, trimmed with Milford granite in rough blocks.

To this list of puddingstone buildings might be added many private structures, including dwelling houses, lodges, stables, etc., especially in the puddingstone districts of Roxbury, Brighton, Newton, etc., and almost invariably these are among the better structures of their class. Aside from its use in superstructures, the puddingstone has had a large and effective use in foundations and basements. Also mention may be made of the important use of puddingstone in landscape architecture and in various engineering works, notably in the park system of Boston, and including arches, bridges, retaining and barrier walls, balustrades, steps, etc.

Behavior and Estimate. — This unique and interesting stone has, practically without exception, given a good account of itself under all the varied conditions of its use. In fact, we have not observed a single instance of serious failure in the way of cracking, scaling, crushing, or disintegration. Although coarsely fragmental in structure, it is essentially impervious to moisture and free from blind seams, and hence not susceptible to injury by frost. Furthermore, the colors, especially of the rusty seam-faces, are eminently stable and permanent, and not subject to alteration, detrimental or otherwise.

Although the character of this stone rather narrowly limits its use, as previously noted, it may fairly be described as well adapted to most of the structures and situations in which it has been used. One cannot but feel, however, that it harmonizes best with its surroundings in the rural districts and in the parks. A special advantage of the puddingstone for use in the city is found, however, in the fact that, because of its color effect, it is, as regards appearance, practically immune against dust and dirt. Under favorable conditions, it is probably unequaled in artistic and picturesque quality among the rough building stones of Boston. As the examples show, it has found its principal and perhaps its most successful use in the construction of churches, and it may, we think, fairly be regarded as peculiarly well adapted to ecclesiastic and landscape architecture.

In view of its satisfactory record, it is with regret that we note the marked falling off in the use of the puddingstone within the last decade, and the fact that its architectural use is now virtually a thing of the past. We are unable to attribute this to a decline in public favor, especially as the later puddingstone structures are equal in importance and rank to the earlier; but we find the explanation rather in the enforced abandonment of the principal quarries with the growth of the city, thus cutting off the supply of the stone.

Sandstone.

The sandstones suitable for architectural use include four principal varieties — brownstone, freestone, flagstone or bluestone, and quartzite; and since these are contrasted in architectural value and adaptability, as well as in lithologic character, they may best be considered separately.

The further subdivision or classification of the sandstones for purpose of description may conveniently be based upon (1) geologic age and (2) geographic distribution. The geological formations of this country from which sandstones of architectural value are chiefly derived are, in order of age: (1) the Potsdam, especially as developed in northern New York, northern Michigan, Wisconsin, and Minnesota; (2) the Medina division of the Silurian, in central and western New York; (3) the Devonian, in southern New York, Pennsylvania, and other states; (4) the Carboniferous, in Pennsylvania, Ohio, and many other states, and the Maritime Provinces; (5) the Triassic, along the Atlantic seaboard from Massachusetts to South Carolina, and in the Rocky Mountains; (6) the Cretaceous, on the Atlantic seaboard south of New York, on the Great Plains, in the Rocky Mountain region, and on the Pacific coast; (7) the Tertiary, only in the trans-Mississippi region, and especially on the Pacific coast.

Brownstone.

Brownstone is the common and economic designation of the ferruginous sandstones, or those sandstones colored and, in part at least, cemented by the brown and red oxides of iron. They are, in this country, derived from several formations of varying character and differing widely in geologic age and geographic distribution, including in the order of age, beginning with the newest, the Triassic, Carboniferous, Medina, and Potsdam. The brownstones of these different formations, it may be added, are, in general, of unlike character and readily distinguished, the oldest being, as a rule, the hardest and strongest, or most metamorphic in character, and often shading into true quartzite.

Triassic Brownstones. — Because of its favorable distribution, within convenient distance of all the large cities of the Atlantic seaboard, the Triassic formation has furnished the principal part of the brownstone used in the eastern part of the country; and, more than any other stone, it gives character, in Boston as also in New York, to the

architecture of the second half of the last century. It varies greatly in texture, composition, and color; but in general it is a medium to coarse-grained rock of dark, reddish brown to red colors, and consisting chiefly of rather angular grains of quartz. Very generally, however, the brownstone is a more or less typical arkose, containing abundant grains of feldspar and scales of white mica (muscovite). In its variations in composition the stone but reflects the character of the older formations of the region (granite, mica schist, etc.) from which it has been derived; and it is its arkose character, chiefly, that distinguishes it from the brownstones of other formations. The grains, especially of quartz and feldspar, are normally coated with the red oxide of iron (turgite), or a highly ferruginous red clay, which forms at once the cement and the coloring agent of the stone. Other things being equal, the architectural value of the brownstone varies inversely as the proportion of mica in its composition, since the mica tends to make the stone shaly and friable.

Although not ranking high among the sandstones in porosity or ratio of absorption, the weakest point of the Triassic brownstones is their susceptibility to injury by the action of frost, and on this account the stone may be regarded as ill suited to use in our climate. It is, however, extremely variable in this respect, the material from some districts and quarries proving much more durable than that from others; and this contrast may sometimes be noted even of stones from the same quarry. The only quarry districts in the Triassic areas represented among the buildings of Boston and vicinity are the Connecticut Valley in Connecticut and in Massachusetts, and northern New Jersey.

Triassic Brownstone of Connecticut (Portland Brownstone). — Although brownstone is quarried at various points in this state, including Portland, Cromwell, East Haven, and Manchester, it varies but little in character; and, furthermore, the material used in Boston has nearly all come from Portland. hence the other localities need not be specially considered.

Occurrence. — The Portland quarries are believed to be the oldest, as they are also among the largest, sandstone quarries in the United States; and they enjoy the great advantage of being situated directly on a navigable river (Connecticut), permitting cheap water transportation to the principal markets. The massive beds of brownstone are approximately horizontal, and divided with great regularity, at wide intervals, by vertical joints, giving the quarries, which may be 180

to 200 feet deep, rectangular outlines, and making it possible to obtain blocks of any desired dimensions.

Description. — The Portland brownstone is prevailingly of a coarse, irregular, and more or less open or porous texture, and limited streaks or layers of coarse, angular gritstone or fine conglomerate are of common occurrence. In composition it is an arkose with a ferruginous clay cement, in which quartz and feldspar are about equally abundant, and in which also mica, chiefly muscovite, is rarely absent, and is frequently a conspicuous feature of the bedding surfaces, sometimes giving the stone a shaly structure. The black mica once present has usually been altered to chlorite, which is sometimes sufficiently abundant to give the stone a greenish tinge in spite of the abundant ferruginous cement. The stratification is usually readily apparent, and often a marked feature of the stone. Four grades of brownstone are quarried: (1) medium-grained (first quality) brownstone, used in high-class architectural work; (2) fine-grained (second quality) brownstone, richest in clay and mica, and most subject to injury by frost action; (3) brownstone of uneven, laminated, and shaly texture (third quality); (4) coarse brownstone (conglomerate), used for rough stone work and bridges.

The Portland and Cromwell brownstones, presumably of the first grade, have been submitted to various tests at the Watertown Arsenal, with the results detailed below.

Compressive Strength. — Portland brownstone: Prism 24 x 3.97 x 5.97 inches; compressed endwise; crushing load 6,173 pounds per square inch of transverse section. Prism 12.02 x 6.00 x 3.97 inches; compressed endwise; crushing load 10,655 pounds per square inch of transverse section. Cubes $2\frac{1}{2}$ to 3 inches, on bed, crushing loads: first quality, 13,655 pounds per square inch; second quality, 13,920 pounds per square inch; third quality, 15,020 pounds per square inch; bridge stone, 9,615 pounds per square inch.

Cromwell brownstone: Approximate 4-inch cubes; maximum loads 17,557 and 16,231 pounds per square inch. Cube, dimensions not given, crushing load on bed, 12,582 pounds per square inch. Ten cubes, $1\frac{1}{2}$ inches on an edge, 7,991 to 15,000, average 10,603, pounds per square inch. Also ten cubes, $2\frac{1}{2}$ inches on an edge, 7,843 to 14,375, average 10,783.5, pounds per square inch.

Transverse Strength. — Portland brownstone: Prism 24 x 6 x 4.01 inches; bedding planes parallel to maximum and minimum dimensions and horizontal; distance between supports, 19 inches; modulus of rupture per square inch, 1,576 pounds.

Cromwell brownstone: Prisms approximately 24 x 6 x 4 inches; on edge (direction of bedding not given); distance between supports, 20 inches; modulus of rupture per square inch, 2,243 and 1,500 pounds.

Shearing Strength. — Portland brownstone: Approximate shearing dimensions, 4 x 6 inches; shearing strength per square inch, 1,392 pounds.

Cromwell brownstone: Approximate shearing dimensions, 4 x 6 inches; shearing strength per square inch, 1,601 and 1,450 pounds.

Modulus of Elasticity.— Cromwell brownstone: Compressive modulus of elasticity per square inch, 7,711,000 pounds, between 100 and 5,000 pounds per square inch.

Coefficient of Expansion. — In water, for 1° F., Cromwell brownstone: .00000549 and .00000544.

Ratio of Absorption. — Portland brownstone, 1 : 40.

Weight per Cubic Foot. — Portland brownstone, 146.8 to 161.4 pounds.

CHEMICAL ANALYSES.

	Portland.			Cromwell.
SiO_2	70.11	72.95	69.94	62.47
Fe_2O_3	4.85	4.12	2.48	3.65
Al_2O_3	13.49	12.82	13.15	10.70
MnO_2	0.35	. . .	0.70	. . .
CaO	2.39	5.57	3.09	10.25
MgO	1.44	2.40	Trace	0.53
Na_2O	7.37	. . .	5.43	2.20
K_2O		. . .	3.30	4.15
CO_2	. . .	. . .	. . .	6.00
Loss	. . .	2.14	1.01	. . .

Although the lime and magnesia which the analyses show are doubtless present in part as carbonates, it is likely that these bases are chiefly in combination with silica in biotite, chlorite, and other minerals, including especially plagioclase feldspar for the lime; and the high percentage of alkalies, approximating the proportions for a

normal granite, also indicates a large amount of undecomposed feldspar as well as mica in the rock, giving it a marked arkose character, and proving that only a relatively small proportion of the alumina is present as clay, a conclusion which is confirmed by the small proportion of water (loss). The iron oxide may be referred in part to the biotite and other dark ferromagnesian minerals; but it undoubtedly exists chiefly as ferric hydrate in intimate union with the clay, this highly ferruginous clay, as previously noted, serving both as cement and coloring agent of the stone, although it is probable that it is cemented in part also by the calcium and magnesium carbonates. Thus interpreted, the analyses are much less unfavorable to the durability of the brownstone than they would appear if the alumina were all present as clay.

Examples. — Comparatively few public or semi-public buildings have been constructed chiefly or largely of the Portland stone, and hence this list is shorter than the important general use of this stone for so long a time would indicate.

1855. Codman Buildings, 32–48 Hanover St. Shows some scaling.

1856. Hotel Pelham, 74 Boylston St., corner Tremont St. Remarkably well preserved.

1862–64. Boston Society of Natural History, Berkeley St. between Boylston and Newbury Sts. First story, on granite foundation, cornice, trimmings, etc. Scaled only where most exposed to dampness or where overloaded.

1864. Rogers Building, Massachusetts Institute of Technology. Columns, cornice, trimmings, etc., with brick on foundation of Cape Ann granite. Shows considerable scaling in shady situations and especially on the under surfaces of projections.

1866–67. Evans House, 174–175 Tremont St. Brownstone front replaced by steel to top of second story.

1872. Harvard Church, Harvard St., Brookline. Trimmed with Bay of Fundy freestone and Pennsylvania serpentine.

1873. New Old South Church, Boylston and Dartmouth Sts. Trimmings only, with puddingstone.

1874. John Hancock House (new), 29 Beacon St. Shows serious scaling.

1892. Church of the Messiah (and chapel), Auburndale. Portland brownstone, mostly rough face, varying in texture from fine micaceous, argillaceous stone to conglomerate. Algæ cover the stone in damp corners. The chapel is older than the church. Portland brownstone, smooth face, somewhat scaled, brick trimmings.

Among the older buildings with fronts, at least, of Portland stone, but the dates of which we have been unable to ascertain, may be mentioned as of special interest:

The Times Building, 3–5 State St. The brownstone front shows extensive scaling.

The building on Hanover St., between Washington and Blackstone Sts., and the buildings numbered 59–67 Hanover St. and 133 Tremont St.

The Union Institute for Savings, Tremont St., corner Lagrange St. Rock face on Lagrange St. and smooth finish on Tremont St. General condition of both very good, although the rock face shows fossil sun cracks and micaceous layers.

Various more or less important examples of the Portland brownstone have been removed in the course of rebuilding operations, and among these may be mentioned the old public library, erected in 1858.

The principal use of the Portland stone, however, has been in the "brownstone fronts" of dwelling houses, especially in those sections of the city proper built up during the three decades from 1850 to 1880, and including considerable portions of the South End and West End districts and the older part of the Back Bay district. North of Dartmouth Street in the Back Bay the Portland stone largely prevails, and nowhere are to be found finer or more instructive examples of its use. The oldest building in this section of the Back Bay is said to be Number 18 Arlington Street, erected in 1860–61. Mt. Vernon and other streets on Beacon Hill and Columbus Avenue and other thoroughfares of the South End also merit prominent mention in this connection.

The Portland stone has also been used very freely as a trimming for granite and other stones and brick in all parts of the city. Its use in any form, it may be added, has been very limited since the early nineties, and chiefly for repairs.

Contrary to the dictates of common sense, the Portland stone, with its strongly marked lamination, has been chiefly or almost exclusively set on edge and usually with the bedding faces exposed to the weather, which is the position most unfavorable to the strength and longevity of the stone. On the other hand, although used to a limited extent with rock face or hammer dressing, the prevailing finish of the Portland stone, as of the brownstones generally, has been sawing followed by rubbing; and this, it may be added, is the finish most favorable to its durability.

Behavior and Estimate. — It may be doubted if any building stones finding important use in this vicinity have been the subject of more unfavorable comment as regards weathering quality and durability than the Triassic brownstones, and particularly the Connecticut or Portland

brownstones, which are among those most largely used, and the use of which has extended over an exceptionally long period, although chiefly confined to the last half of the nineteenth century. The more obvious weak points of this stone are its prevailingly coarse and variable texture, the frequent prevalence of mica and argillaceous material in the composition, culminating in occasional shaly layers, and the marked tendency of the finer and more argillaceous portions, especially, to scale and disintegrate on exposure to frost. Among the good points of the stone, as affecting its durability, may be mentioned the facts that it is reasonably strong for a sandstone, being fully up to the average, so that instances of crushing, cracking, and transverse fracture or shearing due to overloading are rather infrequent, and that it is not subject to chemical deterioration or detrimental change of color.

Disintegration under the influence of a frosty climate stands out, then, as the one grave defect. This is more or less noticeable in nearly all the examples, but the result is of a striking character in comparatively few. Where most marked, in damp and shady situations, as near the ground and on the lower sides of projections, massive blocks may be eaten away for a considerable thickness, and where set, as is usually the case, with the bedding faces to the weather, the stone yields by scaling, and not wholly grain by grain, while where laid on bed, or edgewise to the weather, it is often distinctly etched, the firmer layers and laminæ being left in relief by the erosion of the weaker. The student of this stone quickly discovers that it is not the coarse, irregular, and seemingly friable brownstone which shows most injury by frost action, but rather the fine-grained, argillaceous and micaceous variety, the latter holding water tenaciously, while the former dries out quickly, and usually before the water has time to freeze in it. These facts point to the conclusion that the strongest stone is not necessarily the most durable; and it is equally clear that the record of the Portland stone would be much better had proper care always been exercised in its selection, seasoning, and use.

While the behavior of this stone, often under very unfair conditions, has no doubt tended to check its use, it may fairly be said that its decline in public favor in the last two decades is chiefly due to the same general cause — a change of fashion or public taste — affecting somewhat equally all the brownstones. In conclusion, it may be noted that the Portland stone is manifestly unsuited for carved or relief work, but with this limitation, and especially in dry or protected situations, it

should prove, under intelligent use, a durable, as it certainly is a handsome, stone.

Triassic Brownstone of Massachusetts (Longmeadow Stone). — The quarrying of brownstone in Massachusetts is still more localized and concentrated than in Connecticut; and East Longmeadow, in Hampden County, five miles southeast of Springfield, is practically the only locality producing stone for other than local use. The Longmeadow stone has not been used for so long a period as the Portland stone, but during the later brownstone decades it largely supplanted the Portland stone in this region; and, although but little of it has been used in the last decade, it stands today the principal brownstone of Boston and vicinity. The Longmeadow stone used in this district has come principally from three quarries, on as many different beds, and known as the Maynard, Kibbe, and Worcester. The stone suitable for quarrying occurs in massive beds 10 to 20 feet in thickness, separated by more shaly material, and dipping at angles of 10° to 15° in a general easterly direction. The dip of the beds carries them beneath a rapidly increasing thickness of overlying strata, and the cost of removing this cover narrowly limits the depth to which the stone can be worked profitably. The individual quarries are, therefore, subject to early exhaustion. The stone is so massive and the joints so widely spaced that blocks of any desired dimensions are readily obtained.

Description. — The Longmeadow stone is a massive, homogeneous variety of rather fine to medium texture, and reddish brown to bright brick-red color. In comparison with the Portland stone the grain is finer and much more even, it is rarely distinctly laminated, mica is usually inconspicuous and never a prominent feature, and the color is redder. The color distinction holds especially for the product of the Maynard quarry. In fact, the Maynard stone, more properly red than brown, is the brightest and handsomest sandstone which has been extensively quarried in New England.

For this important brownstone, which is for Boston and Massachusetts essentially a local stone, a fairly full series of tests has been made at the Watertown Arsenal, the principal results of which are summarized here.

Compressive Strength. — Approximate 4-inch cubes, two for each variety of stone; crushing load per square inch of cross section;

Maynard stone, 10,538 and 9,223 pounds.
Kibbe stone, 10,063 and 10,663 pounds.
Worcester stone, 9,656 and 9,869 pounds.

Approximate 5-inch cubes, crushing load per square inch of cross section:

Kibbe stone, 12,210 pounds; quarry not given, 12,330 pounds.

Approximate 6-inch cubes, quarry not given; crushing load per square inch of cross section, 12,619 and 12,874 pounds.

Approximate 6-inch cubes from parts of the front of the Ames Building, corner Kingston and Bedford Streets, destroyed by fire November 28, 1889; crushing load per square inch of cross section:

Maynard stone, 8,704 pounds.
Kibbe stone, 8,745 pounds.
Worcester stone, 7,272 pounds.

Transverse Strength. — Prisms approximately 4 x 6 inches in section; distance between supports, 20 inches; modulus of rupture per square inch:

Maynard stone, 660 and 884 pounds.
Kibbe stone, 1,273 and 655 pounds.
Worcester stone, 987 and 1,189 pounds.

Shearing Strength. — Approximate shearing dimensions, 4 x 6 inches; shearing strength per square inch:

Maynard stone, 1,120 and 1,287 pounds.
Kibbe stone, 992 and 1,308 pounds.
Worcester stone, 1,383 and 1,102 pounds.

Modulus of Elasticity. — Compressive modulus of elasticity per square inch:

Maynard stone, 1,941,700 pounds between 1,000 and 2,000 pounds;
2,127,600 pounds between 3,000 and 4,000.

Kibbe stone, varies from 1,727,200 pounds at 1,000 to
3,024,200 at 8,000 pounds;
1,834,900 pounds between 1,000 and 2,000 pounds;
2,298,800 pounds between 4,000 and 5,000 pounds.

Worcester stone, varies from 2,361,300 pounds at 1,000 to
3,323,300 at 8,000 pounds;
2,439,000 pounds between 1,000 and 2,000 pounds;
1,780,000 pounds between 1,000 and 2,000 pounds;
1,910,000 pounds between 1,000 and 2,000 pounds;
2,898,500 pounds between 3,000 and 4,000 pounds.

Coefficient of Expansion. — In water, for 1° F.

Maynard stone, .00000567.
Kibbe stone, .00000577.
Worcester stone, .00000517.

Weight per Cubic Foot. —

Maynard stone, 133.5 pounds and 132.8 pounds.

Kibbe stone, 133.4 pounds and 134 pounds.

Worcester stone, 136.6 pounds and 135.4 pounds.

The light weight of the Longmeadow stone indicates a relatively high porosity, but, apparently, no determination of the porosity has been published.

CHEMICAL ANALYSES.

Analyses of the rocks of the Kibbe (I), Worcester (II), and Maynard (III and IV) quarries. Analysis I was made by Professor C. F. Chandler, of Columbia University, II and III at the Worcester Polytechnic Institute, and IV at the Watertown Arsenal.

	I.	II.	III.	IV.
Silica	81.38	88.89	79.38	79.51
Alumina	9.44	5.95	8.75	8.54
Oxide of iron	3.54	1.79	2.43	2.51
Lime	.76	.27	2.57	2.70
Oxide of manganese	.11	. .	. .	. .
Magnesia	.28	. .	. .	Trace
Alkalies	. .	.86	4.08	5.26
Carbonic acid, water and loss	4.49	1.83	2.79	1.48
	100.00	99.59	100.00	100.00

A study of the analyses shows that, in comparison with the Portland stone, the Longmeadow stone contains 10 to 20 per cent. more silica (quartz), with correspondingly low percentages of alumina, lime, and alkalies, and practically no magnesia. The feldspathic or arkose character is, therefore, less pronounced, and it is virtually a quartzose sandstone cemented in part and colored by iron oxide and containing rather less clay and much less mica than the Portland stone. It is probable that in some cases, and especially in the Maynard stone, the carbonates contribute more than the ferric oxide to the cementation of the stone; and the high percentage of silica suggests that this constituent also plays to some extent the rôle of a cement.

Examples. — The extensive and important use of this stone during the eighties and nineties gives it a prominent place in the more modern

sections of the city. As in the case of the Portland stone, however, and to an even greater extent, few structures and few façades are built wholly of Longmeadow stone; but except as used for trimmings it is commonly restricted to the first story, separating a foundation of granite from a superstructure of brick. The relatively fine, firm, and uniform texture of the Longmeadow stone, as compared with the Portland stone, insures for the former freer use in elaborate or detailed and carved work.

Soon after 1840. Residence of James M. Codman, Sargent estate, Brookline. Protected by broad eaves and veranda and very well preserved.

1871. Dwelling house, 87 Beacon St. Carving under eaves scaled.

1877. Hotel Nottingham, 25 Huntington Ave.

1880–81. Crane Memorial Library, Quincy, Mass. Worcester quarry.

1881. Channing Unitarian Church, Park St., Newton. Trimmed with Ohio freestone.

1882. Boston Art Club, Newbury and Dartmouth Sts. Kibbe quarry. With brick. Slightly scaled at Dartmouth St. entrance.

1882. Auburndale Station, Boston and Albany Railroad.

1882–83. Y. M. C. A. Building, Boylston, corner Berkeley St. With brick.

1883. Hotel Oxford, 40 Huntington Ave.

1883. Law School, Harvard University, Cambridge. Kibbe quarry.

1883. University Club, 270 Beacon St. Kibbe quarry. Altered in 1892.

1883–84. Spiritual Temple, Exeter and Newbury Sts. Worcester quarry. With Milford granite.

1884. Oliver Ames House, Commonwealth and Massachusetts Aves. McGregory quarry.

1884. Claflin Building, 20 Beacon St.

1884. Massachusetts Hospital Life Insurance Building, 50 State St. Longmeadow stone, underpinning St. George, N. B., granite.

1884–85. Unitarian Building, 25 Beacon St. Slight scaling on steps.

1885. Immanuel Baptist Church, Church St., near Centre St., Newton. Rock face.

1885. Converse House, 348 Beacon St. Maynard quarry.

1885. Converse Memorial Library, Salem St., near Main St., Malden. Small, rock-face blocks.

1885. Hotel Kensington, 687 Boylston St. Rock face and tooled work.

1885. Woodland Station, Boston and Albany Railroad.

1885. Brighton Station, Boston and Albany Railroad.

1885–86. Hollander Building, 202–208 Boylston St. Stone more micaceous than usual.

1886. Newton Highlands Station, Boston and Albany Railroad.

1886. Elliot Station, Boston and Albany Railroad.

1886. Waban Station, Boston and Albany Railroad.

1887. Allston Station, Boston and Albany Railroad.

1887. Newton Lower Falls Station, Boston and Albany Railroad.

1887. Hotel Thorndike, 240 Boylston St. Some stones slightly pitted.

1887. Normal Art School, Exeter, corner Newbury St. Worcester quarry. With brick.

1887. Hotel Victoria, Dartmouth, corner Newbury St. Rock face and tooled work.

1887. Pierce Building, corner Huntington Ave. and Dartmouth St.

1887–88. Boston *Globe* Building, 236 Washington St.

1888. Eliot Congregational Church, corner Church and Centre Sts., Newton. Trimmings, with Milford granite.

1888. Police Station (No. 16), Boylston, corner Hereford St. Shows some scaling and efflorescence.

1888. Reservoir Station, Boston and Albany Railroad.

1889. Niles Building, 27 School St. Shows adaptation for carving.

1889. Cambridge City Hall. With Milford pink granite.

1890. Hooper House, 448 Beacon St. Maynard quarry.

1890. Horace Mann School, 178 Newbury St. With Milford granite and brick.

1890. Abbot House, Garden St., Cambridge. Kibbe quarry.

1890. New England Shoe and Leather Exchange, 114 Bedford St. Brick, entrance of Longmeadow stone.

1891. Pray Building, 646–658 Washington St. Maynard quarry.

1891. Copley Sq. Hotel, Huntington Ave., corner Exeter St.

1891. Newton Centre Station, Boston and Albany Railroad.

1891–92. *Youth's Companion* Building, 201 Columbus Ave. Maynard quarry.

1891–92. Farlow Building, 94 State St. (Longmeadow or Portage.)

1892. Brookline Hills Station, Boston and Albany Railroad.

1893. Longwood Station, Boston and Albany Railroad.

1893. Riverside Station, Boston and Albany Railroad.

1894. St. John's Methodist Episcopal Church, Mt. Auburn St., near Palfrey St., Watertown.

1895. Farley, Harvey & Co., 141 Essex St.

1897. Newton Station, Boston and Albany Railroad.

1898. Huntington Ave. Station, Boston and Albany Railroad.

1898. Faneuil Station, Boston and Albany Railroad.

1898. Trinity Church (Portico), Copley Sq. McGregory quarry. Lintel over door cracked transversely; white efflorescence.

1900. Barristers Hall, Pemberton Sq. Kibbe quarry.

1900. Trinity Place Station, Boston and Albany Railroad.

1901. Hotel Buckingham, 39–41 Huntington Ave.

R. H. White & Co., Entrance on Bedford St. and Harrison Ave. Badly pitted.

New England Building, 200 Summer St. First story Longmeadow or Portage; rough and dirty.

Rowe's Wharf, 350 Atlantic Ave. Entrance of Longmeadow stone

Chestnut Hill Station, Boston and Albany Railroad.

If allowed to cover private as well as public architecture, this list of examples might be extended almost indefinitely in the newer, but not the newest, sections of the city, and especially in the central section of the Back Bay district between Dartmouth Street and Massachusetts Avenue. In fact, in this most important part of the city, built up during the decades when the Longmeadow stone was the principal building stone of Boston, it gives character to the architecture, and the student will find here some of the finest, most varied, and most instructive examples of its use. Like the Portland stone, it has found a very extensive use as a trimming for the light-colored building stones and for brick.

Behavior and Estimate. — Having succeeded the Portland stone in public favor and general use, and belonging, therefore, mainly to a more recent period, the Longmeadow stone has not been so thoroughly tested in use. The decay of a building stone is likely to proceed very slowly at first and to be subject to acceleration; so that, in the case of a sandstone especially, the third or fourth decade is usually far more telling than the first. But although its later use gives the Longmeadow stone a marked advantage in this comparison, there can be no doubt that it is actually, on the average, or in most cases, the more durable stone and much more uniformly durable, matching in this respect its relative uniformity of composition and texture. The relatively free use in elaborately dressed and carved forms, which its finer texture invites, tends, on the other hand, to place it at a disadvantage in the comparison. Scaling under the influence of the frost is not a marked tendency with the Longmeadow stone, and the coarse, heavy scaling often to be noted on the Portland stone is practically wanting. The most manifest signs of decay are a fine granular disintegration, often following the separation of a thin scale, and not infrequently a more or less distinct pitting of the surface. The pitting is not apparently due to clay holes, but finds a better explanation in the solution of the carbonate of lime which the analyses show and which we may assume to be segregated somewhat in concretionary fashion. Among the weak points of the Longmeadow stone may be mentioned also a general tendency to change of color or discoloration, darkening under the influence of dust and organic growths (algæ, etc.) and whitening by efflorescence or the exudation of the lime, possibly as a sulphate. In very few instances has the strength, compressive or transverse, of this brownstone proved inadequate; and the only striking cases are where now and then a lintel or cap is cracked transversely.

The comparative disuse of this excellent stone in recent years appears to be mainly a matter of fashion, a change, possibly only temporary, in the public taste, which gives the preference to the light-colored stones, although it is undoubtedly true that the texture of the now prevalent Indiana limestone possesses a quality of toughness and adaptability to carved and highly finished work not to be found in any of the true brownstones, which are, at the best, relatively tender and friable. The next two decades will probably determine whether or not the limestone is to prove more durable than the brownstone in the acid and dust-laden atmosphere of the city. If not, then the richer and more unchanging color of the brownstone should insure its return to popular favor.

Triassic Brownstones of New Jersey (New Jersey Stone). — The Triassic sandstone of New Jersey, with the associated sheets of trap rock (diabase), extends diagonally across the northern part of the state in a broad, continuous belt from the Hudson River south of the Highlands to the Delaware north of Trenton. The beds dip to the northwest at low angles, and the principal quarry districts lie to the southwest, near the Delaware, and to the northeast in the vicinity of Newark and Paterson. Probably from the northeastern districts only has the brownstone found its way to Boston, where the product of several of the largest quarries has been identified, including those of Newark, Belleville, and Little Falls.

Description. — The general character of the New Jersey brownstone is not unlike that of the Longmeadow stone, except that it is at times rather coarser and more variable. As a rule, the texture is fine and uniform, the lamination indistinct, and mica is, in general, conspicuous by its absence. It is also essentially a highly quartzose granitic or arkose sandstone cemented by iron oxide, silica, and carbonate of lime. The color varies from light brownish gray to dark brown and reddish brown.

We have found records of but few tests of the New Jersey brownstone; and it is not certain how far these represent material actually used in Boston. The following determinations were made by General Gillmore in 1875.

Compressive Strength. — Two-inch cubes. Belleville stone: on bed, 11,700 pounds per square inch; on edge, 10,250 pounds per square inch. Little Falls stone: on bed, 9,850 pounds per square inch; on edge, 9,150 pounds per square inch.

Weight per Cubic Foot. — Belleville stone, 141 pounds; Little Falls stone, 140.6 pounds.

Ratio of Absorption. — Belleville stone, 1 : 27; Little Falls stone, 1 : 34.

Examples. — The great abundance of good brownstone in New England and the fact that New York has afforded a convenient and ample market for the product of the New Jersey quarries explain the rather limited use of the New Jersey stone in Boston. The difficulty of distinguishing it from the Longmeadow stone makes it well-nigh impossible in some cases, and especially with the older buildings, to be certain of the identity of the stone. We have endeavored, however, to exclude from the Longmeadow examples all doubtful cases; but it may well be that among the unclassified brownstone buildings of Boston are many more examples of the New Jersey stone than we have listed here, but probably none others of equal importance; and these few are deemed sufficient for the purpose of a comparative study of the brownstones.

1847–49. Boston Athenæum, 10½ Beacon St. Little Falls quarries.

1861. Arlington St. Unitarian Church, Arlington and Boylston Sts. Belleville and Little Falls quarries.

1865. Central Congregational Church, Berkeley and Newbury Sts. Trimming, with puddingstone.

1873–74. Second Unitarian Church, Copley Sq. Newark quarries.

Jordan Marsh Co., original building, 450–572 Washington St. Belleville quarries.

Liberty Building, 30 Kilby St.

Behavior and Estimate. — Little remains to be said under this head, since the stone so closely matches the Longmeadow stone. In weathering quality it is, perhaps, not quite equal to the latter, being rather more inclined to scale and disintegrate, while pitting is certainly a more marked feature; but we are unable to cite an instance of serious failure from any cause, and it is only fair to the New Jersey stone to note that the examples cited are, on the average, much older than those of the Longmeadow stone. It may be added, however, that since it is at least no better than the Longmeadow stone, it is not surprising that it has not been more extensively used in competition with the latter.

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THE NITRIFYING ORGANISMS IN SEWAGE FILTERS.

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Translated from the German,[1] with the Author's Permission, by A. E. KIMBERLY.

So far as we know the efficiency of the biological process of sewage purification is chiefly dependent upon the activity of microörganisms within the filters. The construction of a purification plant, therefore, must be along such lines as to allow an active development of the organisms in question.

It has been conclusively proven that the life processes of the most important of these organisms are dependent upon the presence of atmospheric oxygen, and that, as a result of their activity, the nitrogen compounds present in sewage are finally oxidized into nitric acid. These organisms include, therefore, the so-called "nitrifying" bacteria. Until the present time pure cultures of these from filters have not been forthcoming. It has not been possible, therefore, to study their biology more closely.

The investigations described in this paper were undertaken at the suggestion of Professor Dr. Günther, director of the Bureau. It was proposed to isolate and study the nitrifying bacteria in sewage filters, and, further, to compare them with the nitrifying organisms present in the soil of cultivated fields.

Winogradsky's[2] nutrient solutions for the nitrite- and nitrate-forming bacteria, respectively, were prepared, sterilized, and put in Erlenmeyer flasks in amounts of about 100 c.c. each. In the flasks were placed coke from the experimental contact beds at the Karolinenhöhe Sewage

[1] Schultz-Schultzenstein, Über die nitrificierenden Mikroorganismen der Filterkörper biologischer Abwässer-Reinigungsanlagen. Mitteilungen a. d. K. Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, Heft 2, 1903, pp. 1–22.

[2] Archives des Sciences Biologiques, Institut Impérial de Médecine Expérimentale, St. Petersburg, 1892, I, p. 88.

Experiment Station at Charlottenburg,[1] soil from the irrigation field, ordinary soil, or sand from the bottom of the settling basin. For the sand and soil tests 2 grams of material were taken. For the flasks containing coke 8 grams were weighed out, more coke being used on account of its having less surface. The contents of each flask is shown in the following table:

I. Soil from sewage irrigation field not flooded for four weeks.
II. Sand from a so-called "Schonfilter."
III. Soil from an uncultivated field.
IV. Coke from a well-matured primary contact bed.
V. Coke from a well-matured secondary contact bed.
VI. Sand from settling tank.

All the samples were collected March 5, 1902. The temperature of the air was 0° C., and within the filters it was 7° C. The flasks which contained the solutions for the nitrite-formers were marked with the Roman numerals, I–VI; those for the nitrate-formers with the Arabic numbers, 1–6. The solutions were kept in an incubator at from 25° C. to 26° C., and were examined daily for ammonia with Nessler reagent, for nitrites with sulphanilic acid and *α*-naphthol, and for nitrates with diphenylamine.

The expected formation of nitrites or nitrates took place in each case, but after different periods of time. The flasks containing coke from the contact bed were the first to show nitrites and nitrates. In two days, flasks IV and V gave a strong nitrite reaction. Flask III, containing ordinary garden soil, did not show nitrites until the fifth day. After five days, the solutions containing sand from the irrigation field and sand from the settling basin gave strong nitrite tests. After six days, in testing for nitrites a brown precipitate was observed in the solutions containing coke. Owing to the very slow growth of both of the nitrifying organisms, it may be concluded that the rapid nitrification in well-ripened contact beds is due to the presence of large numbers of these bacteria on the coke.

The appearance and constant increase in the formation of flocks on the bottom of the flasks containing the nitrite-former solution could be observed during the course of the experiment. In the soil tests the flocks were of a grayish-yellow color; in the coke black-gray. In hang-

[1] Charlottenburg is a municipality three miles west of Berlin, situated on the Spree. At the Westend pumping station, during the years 1898 and 1899, experiments were made upon the disposal of sewage along bacterial lines. As a result of these investigations larger works, experimental in character, were built at Karolinenhöhe, where experiments upon the various methods of sewage treatment have been carried on. — A. E. K.

ing drops containing these flocks a great many species of motile and non-motile bacteria were to be seen. In stained slides from the nitrite-former solutions oval bacteria 1.2–1.5 μ long, 0.8–1.0 μ wide outnumbered all other species; they lay, some singly and some in pairs, with their long sides together. The majority, however, were clumped in amorphous masses, in which they were held by a substance staining much lighter with gentian violet than did the organisms themselves.

These bacteria are completely similar in form to Nitrosomonas, described by Winogradsky.[1] They differ slightly in their staining properties, however, staining very readily with gentian violet. The nitrite-formers obtained by Winogradsky from various kinds of soil, on the other hand, could be stained well only by a half-minute application of a weak solution of malachite green counterstained with a dilute solution of gentian violet.

After six days of observation, subcultures were prepared with two drops from flasks I, IV, V, and VI, these being the ones which nitrified the strongest. They were marked I*a*, IV*a*, V*a*, and VI*a*, respectively. Flask IV*a* worked so energetically that after eighteen days all the ammonia (1 c.c. of a 10 per cent. solution of ammonium sulphate) had disappeared Stained slides prepared from these subcultures showed organisms exactly similar in form to those described by Winogradsky as Nitrosomonas.

In order to eliminate "wild" organisms, two drops were taken from subculture IV*a* to form culture IV*b*, and from this, after the ammonia had disappeared, culture IV*c* was prepared in like manner. From this culture, IV*c*, agar plates were then made. The agar, in a thin layer, was steeped in water for eight days, according to Beijerinck's method. So many other bacteria grew, however, that an attempt to obtain a pure culture of the nitrifying organisms was out of the question. In another trial, where the agar had been steeped for three weeks, there developed still six or seven foreign species. These colonies were so numerous, and grew so much more rapidly than did the nitrifying bacteria, that they spread entirely over the surface of the plates. I therefore abandoned the use of agar and turned my attention to silicic acid media.

There is hardly a better method of preparing silica jelly than that which Winogradsky[2] gives. I have found that a solution of silicic acid,

[1] Annales de l'Institut Pasteur, IV, 1890, p. 213, and V, 1891, p. 92.

[2] Archives des Sciences Biologiques, I, 1892.

corresponding in specific gravity to that given by him, may be obtained by diluting 173 c.c. of a 10 per cent. solution of sodium silicate with 100 c.c. of distilled water, adding 273 c.c. of hydrochloric acid (specific gravity 1.1), and allowing this to dialyze two days with tap water and then with distilled water until no reaction for chlorides is obtained.

I keep in stock large amounts of aqueous silicic acid thus prepared, and also the necessary sterile inorganic solutions. When ready to use, 100 c.c. of the dialyzed silicic acid is placed in a Koch flask with two graduations, one at 100 c.c. and the other at 20 c.c. The solution is then evaporated to a volume of 20 c.c., the necessary amount of sterilized solutions of salts is added, and the media is then poured into Petri dishes and inoculated. The jelly is formed in from four to five hours.

By using this silicic acid media I succeeded in isolating, from cultures obtained from coke from a contact bed, organisms agreeing completely with those described by Winogradsky as Nitrosomonas.

It appears fitting here to mention a few points which are to be observed in working with silica jelly. If the dialyzed and sterilized silicic acid is kept in flasks with rubber stoppers, a marked nitrite reaction is evident after about four weeks upon testing with sulphanilic acid and *a*-naphthol. This silicic acid must, therefore, have a very strong attraction for the small amounts of nitrous acid present in the air of the laboratory. The materials used do not give this reaction before mixing, neither does the freshly dialyzed silicic acid.

Rullmann[1] investigated Winogradsky's fluid media along this line, and found that in solutions kept at room temperature and in flasks stoppered with rubber stoppers nitrite reactions appeared after 130 days; dialyzed silicic acid, on the other hand, showed the reaction in from four to five weeks. This factor of nitrite absorption may give rise to error, as I saw from a control plate of silica jelly uninoculated with the nitrite-formers. In this control, after twenty-one days, a distinct nitrite and nitrate reaction was observed, although no colonies developed whatever, and the amount of ammonia present remained unchanged. The nitrite must have been absorbed from the air. I have been accustomed, therefore, to assume a formation of nitrites and nitrates in silicic acid media only when the ammonia is diminished at the same time.

Further inoculations for obtaining pure cultures of the nitrite-formers were made from flask IV*c*, and for the nitrate-formers from flask 5*c*.

[1] Centralbl. f. Bakteriol., II Abt., Bd. 5, 1899, p. 212.

While Winogradsky says that he succeeded in isolating one single species from soil, using silica jelly to the exclusion of all organic substances, this was not by any means the case in the isolation of the nitrifying organisms from the coke of the contact bed. This was due, perhaps, to the fact that sewage contains a great many species of bacteria not present in ordinary soil.

During March and April, 1902, I strove in vain to prepare agar plates from which a successful inoculation would be possible. Nitrification always took place in the plates and ammonia disappeared. Among the numerous colonies which grew were several which agreed by chance with Winogradsky's description of the colonies of nitrifying organisms, but they proved afterward not to be nitrifying forms. Therefore, as I have said, I gave up my attempts to isolate pure cultures from agar plates.

The method given by Winogradsky was a great aid in the isolation of the nitrifying organisms. This consists in filtering off the zoöglœa through asbestos, washing the asbestos thoroughly with sterile water, and then placing it in a flask containing nitrite-former solution. In this way many but not all foreign organisms were eliminated. In a flask thus inoculated the ammonia (0.1 gram ammonium sulphate) was used up, on the average, in twelve days. With two drops from this flask I inoculated another flask, and from this the first inoculations on silica jelly were made.

On the fourth day, in Petri dishes containing silica jelly media, I saw under a magnification of 180 diameters colonies shaped like little yellow balls or disks, 6.0–8.0 μ in diameter, which refracted light strongly. Slides prepared from these colonies showed long oval bacteria 1.0–1.2 μ in length and 0.8 μ in breadth; there were, however, other organisms present. It happened frequently that I touched only on the side of a colony without obtaining any of it on the needle. For this reason twelve flasks were always prepared with media and were inoculated with the platinum needle after touching a small yellowish colony several times. From these flasks, after a strong nitrite reaction had appeared and the ammonia had disappeared, I again inoculated silicic acid plates with one or two drops of the liquid or with one or two loops of the material. Two species of bacteria beside the nitrifiers always grew, especially upon the surface of the media. The colonies of one of the species were of whitish-gray color, shaped like starfish, and composed of slender rods; while the second kind, which

I call "map colonies" on account of their irregular contours, were made up of short, thick rods. Neither species nitrified, as I have repeatedly convinced myself.

A microscopic examination of the surface of a silicic acid plate made clear to me the cause of these poor results. It plainly showed that the foreign colonies lay immediately beyond the edges of the nitrite-forming colonies, so that both were always fished off together.

It was a test of patience to fish colonies until finally, by chance, I came across one which contained the nitrite-forming organism alone.

Up to this time, moreover, broth cultures had always shown turbidity on account of the admixture of non-nitrifying varieties. Streak cultures on silica jelly had also given no results since the foreign colonies developed faster and spread over the yellow ones.

On the 10th of March, 1902, after fishing nine colonies, I succeeded in obtaining one culture in which no other species than the nitrite-formers were present, as I observed by preparing several stained slides on the following day. From this flask Petri dishes were poured, six with silica jelly and six with washed agar. In both media only the yellow colonies appeared uncontaminated by other species; repeated inoculation into broth produced no turbidity. In this way was obtained *a pure culture of nitrite-forming* bacteria, which in the form of the colony, in the form of the individual bacillus, and in habitat was exactly similar to the Nitrosomonas described by Winogradsky. Moreover, it was obtained from the coke of an experimental contact filter.

Jordan and Richards,[1] in their paper on the nitrifying organism, state that they have isolated a nitrifying organism from sand from an experimental sand filter; they add, however, that there were two or three other species in their flasks. The method employed — namely, continued inoculation into nutrient solutions only, without the intervention of solid media, and inoculation from this — shows conclusively that they did not have pure cultures.

The question now arose, How did these nitrifying organisms find their way into the filters?

To answer this question I have examined, chemically and bacterially, the Berlin domestic sewage collected at Schöneberger Strasse pumping station. The fresh sewage thus obtained showed upon repeated examination an alkaline reaction, albuminoid ammonia 65.6 parts

[1] Massachusetts State Board of Health Report, 1890, p. 878.

per million, generally no nitrites, or rarely traces of them, and never any nitrates.

I divided a sample of this sewage, collected in sterile vessels, into two portions, placing each in an Erlenmeyer flask closed with a sterile rubber stopper. One of the samples was sterilized in streaming steam on two successive days, one-half hour each day. Both flasks were then placed in an incubator at from 25° C. to 27° C. and were examined after eight days The sterilized sewage held its ammonia unchanged, and showed, as when fresh, a slight trace of nitrites, but no nitrates. In the flask containing unsterilized sewage the ammonia had decreased, the nitrite reaction had become stronger, and a small amount of nitrates could be detected. After fourteen days, the ammonia had disappeared, the nitrites were still low, but the nitrates had become very high. The sterilized sewage held its initial constituents unchanged.

At the same time with these experiments, inoculations with sewage were made upon plates containing silica jelly and the nutrient salts required by the nitrite-formers, as follows:

a. With two drops of sewage.

b. With one drop of sewage.

c. With three loops full from *a*.

Various colonies grew upon the plates, among which were several exactly similar to those of the nitrite-formers, and stained preparations of the organisms were found to agree completely with the nitrite-formers in their microscopic characters. A piece of the silica jelly the size of a pea taken from the Petri dish with a sterile platinum spoon showed five days later a weak nitrite reaction. This test was repeated three days later and a strong nitrite reaction was observed. After about three weeks high nitrites and nitrates were found in the media from plate *a*, but no ammonia whatever. The cultivations were kept in a moist chamber, as was the case with all plates containing silica jelly. The isolation of a pure culture of the nitrite-former found in the sewage was given up on account of the before-mentioned difficulties.

It is to be noted, also, that the flask containing unsterilized sewage was examined again after four weeks, and neither ammonia, nitrites, nor nitrates could be detected. Subsequently, therefore, denitrifying organisms must have developed, the number of these species, according to A. Maassen,[1] being very great.

[1] Arbeiten aus dem Kaiserlichen Gesundheitsamt, XVIII, Heft. I, 1901.

Similar experiments have recently been published in the second report of the Royal Commission on Sewage Disposal in London.[1] These had to do, not with the nitrite- and nitrate-formers as such, but with the absence of nitrification when both sterile sewage and sterile coke are used, and the occurrence of nitrification when sterile coke is used with non-sterile sewage.

I have also repeatedly inoculated sterilized sewage with a drop of a fresh, pure culture of the nitrite-former, and have carried along control experiments with sterile sewage alone. In the inoculated flasks, after from six to eight days, nitrite-formation set in strongly, together with a lowering of the ammonia content. After subsequent inoculation with a pure culture of a nitrate-former (see below) the oxidation continued promptly to the nitric acid stage. Sterilized sewage may be kept indefinitely without changing in reaction. It is thus proven that the nature of the Berlin sewage is such that the nitrite and nitrate bacteria can exist in it and are able to nitrify the ammonia.

Finally, I inoculated Petri dishes containing silica jelly and the inorganic salts proposed by Winogradsky for the nitrite-formers with three, four, and six drops of fresh sewage, respectively. Oxidation of the ammonia took place as was expected, and among the numerous colonies that grew there were many that resembled exactly those of the Nitrosomonas of Winogradsky; stained preparations of such colonies also showed bacteria which were identical with the Nitrosomonas. By inoculating solutions containing ammonium salts with these bacteria nitrification was produced. I have not endeavored to obtain a pure culture of Nitrosomonas from this material, being unwilling to renew the tedious struggle with its companions, which are so difficult to separate.

From the foregoing results it is clear that the nitrifying organisms are brought into filters by the sewage itself, although, of course, these bacteria may reach the filters in other ways.

The question next arose, How do the nitrite-formers gain access to sewage? One possible source is the soil which comes into the sewage from the washing of potatoes, roots, etc. In sand and in cultivated land the organisms of Winogradsky have already been demonstrated.

In order to inquire into this matter still more closely, I inoculated

[1] Second Report of the Royal Commission on Sewage Disposal, London, 1902.

silica jelly plates with from ten to fifteen drops of Berlin tap water. Nitrification set in and the typical small yellow colonies appeared, but only in small numbers. In stained preparations from such colonies I saw bacteria likewise entirely similar to Nitrosomonas. In the silica jelly treated with tap water the ammonia disappeared after from four to five weeks.

Further, I collected a sample of water from a public well in Wilhelmstrasse, Berlin, added a sterile solution of the salts in proper concentration as recommended by Winogradsky for Nitrosomonas cultures, and kept the same in the incubator at from 26° C. to 28° C. After three weeks nitrification took place, giving a distinct reaction for nitrites; forty-two days later the ammonia had disappeared. Next I added to 100 c.c. of the water 1 c.c. of a 10 per cent. solution of ammonium sulphate. After twenty-one days merely a trace of ammonia could be detected, the nitrites having from the start continually increased. Finally they almost entirely disappeared, and a very decided nitrate reaction set in, probably due to the activity of the nitrate-formers. In stained preparations from this solution, besides many other bacteria, there were some exactly similar to the Nitrosomonas of Winogradsky.

Finally, by courtesy of Mr. Anklam, chief engineer of the Berlin Water Works at Friedrichshagen, I obtained a sample of sand from one of the filters that had just been drained. This sand, as I received it, gave a very strong test for nitrites and a weak nitrate reaction. A stained preparation of a drop of water from the sand showed a great many different kinds of microörganisms. A sample of this sand treated with Winogradsky's Nitrosomonas solution showed slow but steadily increasing nitrification. The remainder, which was kept exposed to the air, had lost its nitrite content in two days and showed only a strong nitrate reaction.

The sample was not tested further, as the detection of the nitrite- and the nitrate-formers in sand did not appear to be necessary. The passage of these organisms into the city water appears, however, to be very natural.

It now seems justifiable to conclude that the nitrifying bacteria in (Berlin) sewage, in part at least, have their origin in the water supply. Assuming that the conditions at Charlottenburg are similar, it may be concluded that the presence of nitrifying bacteria in the contact bed at Karolinenhöhe is, in part, due to the presence of these organisms in the city sewage and in the city water supply. These are, however,

not the only ways by which the nitrifying organisms are introduced into filters. On account of the very widespread occurrence of these species of bacteria in nature, the possibility of their gaining access to filters is very great.

Jordan and Richards[1] have made observations on surface waters of Massachusetts, and their results must be briefly mentioned. Examinations of a series of surface waters at intervals of from two to seven days after their collection showed that the organic matter in suspension decayed in about seven days, as was shown by the increase of free ammonia. In fourteen days, the free ammonia had disappeared and nitrites were formed which reached a maximum in about three weeks. After twenty-eight days, all the nitrogen was converted into the form of nitrate. Celli and Marino-Zucco[2] have isolated from water, bacteria which caused the formation of more nitrites in water containing ammonia than would have been formed had the water remained uninoculated.

Parallel with the researches just described I tried to isolate the *nitrate-forming* organism from the coke filters at the sewage purification plant at Karolinenhöhe.

It is scarcely necessary to mention that on account of the large number of organisms in the sewage the difficulties of isolation were similar to those encountered with the nitrite-former. The work was still more difficult on account of the fact that there were present in the filters bacteria which in colonies on agar and silica jelly were almost exactly similar to those described by Winogradsky. I have fished such colonies repeatedly and I have found that they did not nitrify. In this case, also, I at last succeeded in isolating a *pure culture*, and this was when I found by chance colonies of the desired organism, over 50 μ in diameter, spread over the surface of the silica jelly.

The method used was the same as that in the case of the Nitrosomonas. It was surprising that the final difficulty in obtaining a pure culture was to remove from the media a slowly growing mold which continually appeared. (The study of this fungus will be taken up later.) This fungus possessed no nitrifying power. The presence of nitrous and nitric acids is favorable to its development, but I have never observed it in solutions containing ammonium salts. The nitrate-former

[1] Massachusetts State Board of Health Report, 1890, p. 865.

[2] Rendiconti della accademia dei Lincci, Roma, 1886.

isolated from sewage appears to be exactly similar to the "Nitrobacter" cultivated by Winogradsky.

Now let me give an account of the *morphology and biology* of both of the organisms, the one oxidizing ammonia, the other nitrous acid in its salts.

I have held absolutely to the methods given by Winogradsky. For the preparation of slides I used his method, consisting of a preliminary staining with a dilute solution of malachite green, followed by rinsing, and then by a counterstain with methyl violet. In this way I always obtained good specimens. Later I tried to stain the nitrite-formers with a slightly stronger solution of methyl violet alone, and that also gave good results. Since then I have stained all slides with methyl violet only. Unequal staining of individuals (plasmolysis) I have noticed only in old cultures; I have not succeeded in staining the flagella of the nitrite-former. The flagella of the nitrate-former were observed, stained exactly as Winogradsky shows in photomicrographs.[1] This result was obtained very often by simply heating with methyl violet on the cover glass. I was also able to stain the cilia of the nitrate-former by Löeffler's mordant method. The nitrate-former stained with decidedly greater difficulty than did the nitrite-former; good specimens were generally obtained only after slightly warming the stain on the cover glass.

In cultivating both of the organisms in solutions and in jelly I can only confirm Winogradsky's methods, which I have followed rigidly with the best results. The presence of inorganic substances only is the most favorable condition for development. Neither organism will grow, generally, in broth, even with the addition of the respective nutrient salts (ammonium carbonate and sodium nitrite). The addition of iron (0.4 gram ferrous ammonium sulphate per liter) to the solutions, which I employed for a time, has been discontinued, since a satisfactory growth can be obtained without iron, and since the precipitate of basic ferric hydrate makes the examination of the zoöglœa more difficult. By the addition of magnesium carbonate, prepared and sterilized by boiling before use just as described by Winogradsky, I was able to see how the little particles of this salt were surrounded by the zoöglœa of the bacteria and were gradually dissolved. The consumption of carbonate of magnesia was so great that I was able to add three

[1] Archives des Sciences Biologiques, St. Petersburg, I, p. 98, 1892.

1-gram portions in the course of two months. Later, in order to have only dissolved substances in the nutrient solution, I used 1.6 c.c. of a 10 per cent. solution of anhydrous sodium carbonate for every 100 c.c. of nitrite-former solution instead of magnesium carbonate. The results were excellent. The addition of 0.4 gram of anhydrous sodium carbonate appeared to interfere with the growth of the nitrite-former; I therefore discontinued it.

The use of sodium carbonate gave me the opportunity of observing the continual decrease of alkalinity during the activity of Nitrosomonas. The reaction became after a time neutral to phenolphthalein and, later, acid. Repeatedly in titrating 1 c.c. of an old culture with phenolphthalein as indicator, I noticed that the end-point appeared only after the addition of from 0.5 to 0.6 c.c. of one hundredth normal caustic potash. The fluid had actually become acid, while freshly prepared nitrite-former solution containing sodium carbonate gave an alkaline reaction. The nitrifying activity of the organisms was coincident with this decrease in alkalinity. I have observed several flasks with pure cultures of the nitrite-formers which, in spite of being kept for four weeks at 28° C., had not entirely lost their ammonia because of the absence of carbonate. I was able again to hasten nitrification by adding sodium carbonate from time to time.

Although Godlewski[1] found that Nitrosomonas could assimilate only free carbonic acid, yet Winogradsky's results, as well as mine, show that this organism can draw its needed carbon from the salts of carbonic acid as well as from the free acid. It is another question, however, whether it can assimilate all the carbon of the carbonic acid which the subsequently formed free nitrous acid has liberated. This question, I think, must be answered in the negative, on account of the relatively large amount of carbonate consumed and the proportionately small amount of organic matter formed. In a flask containing a pure culture of the nitrite-former, in which nitrification had been active for two months, and in which 0.4 gram anhydrous sodium carbonate had been used up (the reaction was acid), the precipitated zoöglœa filtered off and dried over sulphuric acid was found to weigh only 0.0016 gram.

Using sodium instead of magnesium carbonate I obtained just as good zoöglœa formation, and, moreover, without the disturbing crystalline particles. Also, when sodium carbonate is used a deficiency of ammonium salt or of carbonate prevents rapid zoöglœa formation. I

[1] Centralblatt f. Bakteriol., Abt. II, Bd. 2, 1896, p. 458.

further observed this phenomenon whenever through oversight a flask was not placed in the incubator, but instead remained over night at about 10° C. The zoöglœa is white, appearing in older cultures as white-yellow flocks without any particular form. The flocks could be removed with the platinum needle and dried and weighed as described above. Under the microscope one can see that these formless masses consist of small, individual ball-shaped conglomerates of bacteria, held together by a substance staining with much less intensity than the organisms themselves.

I could never observe a zoöglœa stage alone with the nitrite-former, for a monad stage was always simultaneously present. If I took a drop from the surface of a pure culture of the nitrite- or the nitrate-formers which showed flocks of zoöglœa on the bottom, and examined it in the hanging drop, I always found a distinctly motile organism. If I took a drop from the bottom of the flask, I then saw in the flocks themselves absolutely motionless bacteria; outside these, however, there were bacteria moving slowly in and out amid the heaps of zoöglœa.

Besides these ordinary conditions, I noticed also, generally on the seventh to tenth day after the preparation of a fresh culture, the clouding of the liquid before zoöglœa formation, as described by Winogradsky; and in hanging drops at this time I noticed a more rapid movement of the bacteria than at any other time, just as in the monad stage described by him.

With the nitrate-former I could not observe a stage with especially rapid movement. However, as Winogradsky found, I saw the strong agglutination of a portion of the bacteria on the walls of the flask, the glass having become thereby opalescent. If the flask be emptied, washed out with sterile water, and refilled with nitrite-nutrient solution, a distinct increase in the intensity of the reaction for nitrites may be observed after four to five days, and numbers of bacteria may be found in hanging drops.

I observed a zoöglœa stage with the formation of white flocks with the nitrate-former also. I have not noticed the zoöglœa stage alone, but always accompanied by the non-motile and motile forms.

According to my observations, the nitrate-former consumed very much less carbonate than the nitrite-former. It also dissolved very much less magnesia, so that I was never obliged to renew the amount of magnesium carbonate in a culture of the nitrate-former if I had used this salt

for neutralization or as a source of carbonic acid (see above). On the other hand, the change from nitrite to nitrate was a very significant one. Thus, for example, 0.5 gram of sodium nitrite C. P. (Merck) was oxidized in fifteen days. It is to be noted that according to the literature on the subject sodium nitrite is scarcely obtainable in trade free from nitrates. The cultures of the nitrite-former consumed 1 c.c. of a 10 per cent. solution of ammonium sulphate on an average in from twelve to fourteen days.

With silica jelly also, as Winogradsky states, it was possible to note the gradual disappearance of the ammonia or the nitrites by removing portions of the medium and treating them with Nessler reagent or with sulphanilic acid and *a*-naphthol.

In order to ascertain what salt of ammonium the nitrite-former could oxidize most easily, I inoculated the following solutions:

1. Nutrient solution with ammonium sulphate.
2. Nutrient solution with ammonium carbonate.
3. Nutrient solution with sodium ammonium phosphate.
4. Nutrient solution with ammonium hydrate.

In 3 the ammonia disappeared much more slowly than in 1 and 2. In 1 the disappearance of the ammonia took place in from twelve to fourteen days; in 2, after ten days; in 3 it had not disappeared after twenty-one days (through an oversight flask 3 could not be further examined). I later repeated the experiment with free ammonia uncombined with an acid, using each time an amount corresponding to 0.1 gram of ammonium sulphate, that is, 0.1 c.c. of a 25 per cent. ammonia solution.

It appears that free ammonia in general cannot be oxidized by the nitrite-former. Winogradsky and Omeliansky[1] have found that 0.005 per cent. of ammonium hydrate checks the activity of the "Nitrobacter," and that 0.015 per cent. prevents it entirely. I did not repeat the experiment with sodium ammonium phosphate, since on each trial tertiary phosphate was precipitated.

It appeared important to try a series of experiments in order to obtain practical results showing what chemical substances from hospital sewage, trade wastes, etc., could have an injurious effect upon the nitrifying activity of the bacteria in sewage or in filters. I studied,

[1] Centralblatt f. Bakteriol., Abt. II, Bd. 5, 1899, p. 329.

therefore, the effect of acids, phenol, sublimate, and chloride of lime upon the growth and the nitrifying power of the nitrite-former.

Such amounts of titrated solutions of 1, acetic acid; 2, lactic acid; 3, oxalic acid; 4, sulphuric acid; 5, phenol; 6, chloride of lime; 7, sublimate, were added to the usual nitrite-former solution, that in the respective flasks there was present a 0.1 per cent. solution of the substances 1 to 6 (for the sublimate see table). I have already mentioned the fact that free ammonia has an injurious effect. The following table shows the results of the experiments.

TABULATED RESULTS OF THE EXPERIMENT OF OCTOBER 16, 1902.

	Elapsed Time.							
	Six days.		Eighteen days.		Twenty-two days.		Twenty-seven days.	
	NH_3	N_2O_3	NH_3	N_2O_3	NH_3	N_2O_3	NH_3	N_2O_3
1. 0.1 per cent. acetic acid	***	* Zoöglœa.	***	**	***	**	*	***
2. 0.1 per cent. lactic acid	***	* Slight zoöglœa.	***	**	***	**	*	***
3. 0.1 per cent. oxalic acid	***	*	***	**	***	**	**	***
4. 0.1 per cent. phenol	***	* Slight zoöglœa.	***	**	***	**	**	**
5. 0.1 per cent. sulphuric acid	***	Traces clear.	***	0	***	*	**	**
6. 0.1 per cent. commercial chloride of lime	***	0 clear.	***	*	***	*	***	**
7. 0.1 per cent. sublimate[1]	***	0	***	Trace.	***	*	***	*
8. Control	***	** Zoöglœa.	***	**	***	***	0	***

*** For ammonia, precipitate with Nessler.
** For ammonia, strong yellow color with Nessler.
* For ammonia, a weak yellow color with Nessler.
*** For nitrous acid, brownish-red precipitate with sulphanilic acid naphthol.
** For nitrous acid, deep red color.
* For nitrous acid, decided pink color.
0 No reaction.

[1] In mixing this solution a strong precipitate of mercury ammonium chloride formed, so that surely only very little mercuric chloride remained in solution.

On the twenty-second day of the experiment hanging drops from all of the flasks, except those containing sublimate and chloride of lime, showed motile bacteria, and under the microscope these were found to be similar to the nitrite-formers. At the start the contents of all the flasks was acid, except the control, which was alkaline. It is evident, therefore, that 0.1 per cent. solutions of these substances while checking the growth of the nitrite-former do not entirely prevent it. Domes-

tic sewage contains, if at all, scarcely ever more than 0.1 per cent. of phenol or more than traces of sublimate, the latter, moreover, being to the greatest part combined with the soaps and albuminous substances in the sewage. The harmful effect of the sublimate was the greatest in spite of the precipitate mentioned above.

The same series of experiments with 0.5 per cent. solutions showed a lessening of the growth and of the activity of the nitrite-formers, and in no case was zoöglœa formation observed. A distinct nitrite reaction was obtained only with the 0.5 per cent. acetic acid after twenty days.

An interesting point in the biology of the nitrite-former is that although 0.1 per cent. sulphuric acid is sufficient to prevent its growth, yet it develops and can form nitrates in weak solutions of organic acids.

When a solution containing potassium phosphate, ammonium sulphate, and sodium chloride, but no carbonate, was inoculated with a pure culture of Nitrosomonas, nitrites were formed, but very slowly.

In order to ascertain whether the oxidation of the ammonia could be obtained through physical causes, as by passing solutions containing ammonium salts through sand or soil or through coke, I started the following two series of experiments.

1. Sand was thoroughly washed, ignited for one hour in a muffle, and, after cooling, placed in two separatory funnels. (NOTE. — The separatory funnels had glass wool over their respective outlets to avoid loss of sand.) By the ignition the sand had acquired a strong alkaline reaction which could not be removed by continued washing with sterile distilled water alone. It was, therefore, treated with hydrochloric acid, neutralized with a sterile solution of sodium carbonate, and then washed with sterile distilled water.

Funnel Number I, containing one-half a liter of sand, was inoculated with 15 c.c. of a strongly oxidizing pure culture of the nitrite-former. Funnel Number II, containing a like amount of sand, was not inoculated. For twenty-one days I added to each funnel daily Winogradsky's nitrosomonas nutrient salt solution; this remained in the sand for from one to two hours and was then allowed to run out. After the nitrite present in the inoculating liquid had been washed out, the water from funnel Number I gave a nitrite reaction, weak at first but gradually increasing in intensity. Ammonia was always present, but no nitrates. In funnel Number II nitrites and nitrates were never observed, the ammonia test being given throughout without any reduction in intensity.

Further, two separatory funnels of 1,500 c.c. capacity were filled with sand from a cultivated field. Before use the sand had been exposed to streaming steam for eight days, two hours each day. A gelatin plate was then prepared to test this sand, and as no colonies developed in three days the sand was considered sterile. Funnel Number I was then inoculated with 10 c.c. of a strongly oxidizing pure culture of Nitrosomonas. Funnel Number II was not inoculated. Both funnels were at first filled daily with a 0.1 per cent. sterilized solution of ammonium sulphate; later a 0.025 per cent. solution of this salt was used in order to approach nearer to the conditions of sewage. The solutions were left in the sand-filled funnels for two to three hours; they were then allowed to drain out. From the beginning the effluent from funnel Number I showed a very strong nitrite reaction. The effluent from funnel Number II never gave more than traces of either nitrites

or nitrates. After twenty-eight days the sand in funnel Number I, which had been inoculated with Nitrosomonas, was in addition seeded with 5 c.c. of a strongly oxidizing pure culture of the nitrate-former, and was then treated daily with a 0.025 per cent. solution of ammonium sulphate (as described above). The solution was allowed to run out after two hours. The effluent from this time on showed only a weak nitrite reaction, but a strong nitrate reaction.

2. The same experiments were then repeated with sterile coke from 3 to 8 mm. in diameter, using the large separatory funnels. From the start a 0.025 per cent. solution of ammonium sulphate was used. The results were the same as in the previous experiments. In the sterile uninoculated coke, also, neither nitrites nor nitrates were formed.

By these experiments I believe that I have proven that it is not justifiable to assume a physical or a chemical oxidation of ammonium salts by sand, by cultivated soil, or by coke, but rather that this oxidation is brought about entirely by the two nitrifying bacteria found in soil by Winogradsky. This is in accordance with the fact that newly constructed filters must first be "matured." As to the "maturing" stage, I believe that energetic nitrification is not to be expected until a sufficient number of Winogradsky's nitrifying bacteria have developed upon the surface of the coke or of the sand.

In England some authorities go so far as to place the presence of a certain amount of nitrates among the requirements of the effluents of contact beds. The judgment of purification according to the amount of the nitrate in the effluent is still questionable. At the same time, it would appear to be feasible to determine by experiment whether the time of ripening could be shortened *by artificially inoculating recently constructed filters with nitrifying organisms.* Similar proposals have already been made by Dibdin, Scott-Moncrieff, and others. Whether actual experiments have been undertaken is not known. We have had in mind such experiments ever since the establishment of our Bureau.

In conclusion I should like to observe further that as a supplement to the experiments above cited I am engaged in studying the effect of substances occurring in manufacturing wastes upon the life processes of the nitrifying bacteria.

Briefly summarized, the results of my work may be stated as follows:

1. On the coke of biological filters Winogradsky's nitrifying organisms are present.

2. For their isolation the silica jelly media proposed by Winogradsky is strongly recommended.

3. The microörganisms isolated by Winogradsky are introduced into filters by the sewage itself (although it is not to be concluded that there

is no other way in which small numbers of the nitrifying organisms gain access to filters). These organisms were found in Berlin sewage as well as in Berlin spring water and tap water.

4. I have not been able to find upon the coke of biological filters any nitrifying organisms other than those discovered by Winogradsky.

5. Sterilized sewage containing ammonium salts may be kept for an indefinite time without losing its ammonia. If such sewage be inoculated with the nitrite- and the nitrate-formers, the ammonia is soon oxidized, first to nitrites and then to nitrates. A condition of equilibrium is then reached, no further change taking place.

6. Unsterilized sewage kept without inoculation loses its ammonia in time. Nitrites and nitrates make their appearance, and these disappear after some time (denitrification).

7. The optimum temperature for the nitrifying organisms lies between 28° C. and 30° C. If kept at 53° C. for fifteen minutes these bacteria are affected; that is, they show no motility in hanging drops; when brought again to 28° C., however, they are able to nitrify; at 60° C. to 65° C. they are killed in forty-five minutes.

8. Slight amounts of organic acids, such as acetic, oxalic, and lactic, up to 0.1 per cent., interfere but little with the growth of the nitrifying organisms; they retard their nitrifying activity only. Commercial chloride of lime and phenol up to 0.1 per cent. act similarly.

9. 0.5 per cent. solutions of the above-named organic acids, as well as of phenol, commercial chloride of lime, and inorganic acids, completely prevent growth and nitrification.

10. Free ammonia entirely prevents the growth and activity of the nitrifying organisms.

BOOK REVIEWS.

The Metals.[1]

A person desiring to look into the history of metals had formerly to consult mainly works on the history of chemistry, such as those of Kopp[2] and Hoefer,[3] as special works on the subject (Zippe,[4] Rössing[5]) were short and rare, and metallurgical works, with the exception of Volume I of Karsten's[6] treatise, give little information. These publications treat mainly of the first records of occurrence of ores, of the uses of metals, and of production, and occasionally of primitive methods of ore treatment. Dr. L. Beck[7] was the first to consider historically the technology of a single metal in his monumental treatise, "The History of Iron: Its Technical Processes and Agency in Civilization."

The volume under consideration aims to give in a single book the history of all the metals, including those of rarer occurrence, forty-one in all. The plan is to discuss the history, the methods of treatment, and the uses of each metal, tracing them from ancient to modern times; to outline briefly the metallurgical history of the different countries which have been or are still prominent in the output of the several metals; to enumerate the ore-forming minerals; and to bring together in tables and diagrams the statistics of production and of prices from the earliest records down to 1902. The main part of the book is devoted to the history of metallurgical treatment of the metal-bearing ores, following the history of each metal from the imperfect methods used at first through the various improvements to the processes in common use today, of which a concise description is given. An attempt is

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[1] Die Metalle, Geschichte, Vorkommen und Gewinnung nebst ausführlicher Productions- und Preiss-Statistik. By B. Neumann, Ph.D. Halle a. S., Knapp, 1904, pp. 421. Mark 16.

[2] H. Kopp, Geschichte der Chemie, 4 vols., lvii + 1701 pp., Brunswick, 1843–47; also Beiträge zur Geschichte der Chemie, xi + 530 pp., Brunswick, 1869; and Die Entwickelung der Chemie in der Neueren Zeit, xxii + 854 pp., Munich, 1874.

[3] F. Hoefer, Histoire de la Chimie. 2 vols., xviii + 1019 pp. Paris, 1842–43.

[4] F. H. M. Zippe, Geschichte der Metalle. xvi + 364 pp. Vienna, 1857.

[5] A. Rössing, Geschichte der Metalle. viii + 274 pp. Berlin, 1901.

[6] C. J. B. Karsten, System der Metallurgie. 5 vols., xxxiv + 2346 pp., 1 atlas with 51 plates. Berlin, 1831.

[7] Geschichte des Eisens. 5 vols. Braunschweig, 1891–1903.

made to compare the different processes by the yield in metal and the cost of treatment, a thing possible only in rare cases.

This is the first time, it is believed, that a history of the technical development of metallurgy has been attempted. If we state that the book has received the first award in a competition offered by the well-known Prussian Society for the Development of Industry, we cannot but help being at once favorably inclined toward the work. In looking over with some care the metallurgical part, one can easily understand why the author should have been successful in the competition, for it is well done. The arrangement is good, the story is told in a clear and concise way, the technical data are sufficient to form a general idea of the value of the different processes, and enough references are given to show whence much of the rare information has been derived.

As to the purely historical part of the several metals, especially of those which were known to the ancients, the author might have enlightened his reader more in regard to the publications he had consulted. It seems to the reviewer that the volume would have gained much in value if at the end of each chapter there had been given a bibliography of the metal considered. It is hoped that the author may soon remedy this omission by an appendix, and thus correct the only serious defect we can find in the otherwise excellent work.

H. O. Hofman.

The American Institute of Electrical Engineers.[1]

The papers read before the American Institute of Electrical Engineers during the year 1902 are so voluminous that it has been necessary to divide the *Transactions* for that year into two volumes, of which only the one covering the first half of the year, Volume XIX of the whole series, has appeared in the bound form.

Each regular meeting is devoted to a special subject. Those discussed in the present volume are: methods of illumination, the electric railway, high tension circuits and protection of apparatus, electro-chemistry, telephony, electric elevators, electric railroading, and electricity in the army and navy. The volume closes with the proceedings of the annual convention at Great Barrington, which includes a series of papers

[1] Transactions of the American Institute of Electrical Engineers, January to July, 1902, XIX; 10 + 1234 pp., ill., plates, 8vo. New York, 1903.

and discussion in regard to the education of electrical engineers that will be read with much interest and profit by all who are engaged in technical instruction.

Systematic Organic Chemistry.[1]

The aim and scope of this book are clearly given in the following extracts from the preface: "At the time of writing, the only general and fairly systematic procedure for the identification of previously described organic compounds of all classes is that which may be conveniently designated the Method of the Empirical Formula. In following this procedure a determination of the percentage composition is first made. The molecular weight is next determined or conjectured. From these data an empirical formula is calculated. The properties of the substance are then compared with those of all the known compounds possessing this formula by reference to their scattered literature, for which Richter's 'Lexicon der Kohlenstoff-Verbindungen' now furnishes a very complete index. . . . The indispensable key to the use of this method is proficiency in ultimate organic analysis, whose difficult technique is fully mastered only by long practice. The performance of the combustions, which must be made in duplicate to secure certainty, is at best a time-consuming operation; and even after reliable results have been attained, it is further necessary in order to fully identify a compound to resort to a study of its physical properties, chemical behavior, and perhaps to a molecular-weight determination." In order to do away with this laborious method and facilitate the identification of organic compounds, the author has worked out a system which rests "upon a classification designed to secure for the carbon compounds those advantages which have been already so long enjoyed in botany and other branches of natural history through the use of systematized descriptions of salient characteristics. The compounds, or chemical 'species,' have been first grouped into 'orders' on the basis of their qualitative elementary composition; then into 'genera' (aldehydes, acids, phenols, etc.), usually on the basis of be-

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[1] A Method for the Identification of Pure Organic Compounds by a Systematic Analytical Procedure Based on Physical Properties and Chemical Reactions. Vol. I. Containing Classified Descriptions of about 2,300 of the more Independent Compounds of Carbon with Hydrogen and with Hydrogen and Oxygen. By Samuel Parsons Mulliken, Ph.D., Instructor in Organic Chemistry and Organic Analysis at the Massachusetts Institute of Technology. New York: Wiley, 1904. xii + 264 pp. $5.00.

havior in simple chemical tests; and finally arranged in each genus according to the increasing value of some readily determined constant like the melting-point or boiling-point. The name of each species is followed in the tables by a brief specific characterization enumerating some of the simpler properties of the substance that have genuine analytical significance, and then, whenever possible, by detailed directions for preliminary and corroborative chemical tests which can be performed with small quantities of material. . . . The claims to admission to this volume of every compound of carbon with hydrogen or with hydrogen and oxygen that receives mention in the second edition of Beilstein's great 'Handbuch der organischen Chemie' and its supplements issued prior to January, 1902, have been separately passed upon, and about 2,300 selected as deserving mention in the tables. . . . The most important intentional omissions are: substances whose claims to recognition as distinct chemical species are not generally accepted; uncrystallizable syrups that cannot be distilled without decomposition; the oily and fatty glycerides; those glucosides and synthetic sugars of which specimens could not be obtained for examination."

In Chapter I are given detailed directions for carrying out the method of identification devised by the author. After the compound is obtained in a pure condition its physical properties and the elements present are determined. General tests to discover to what genus the compound belongs are next made. These tests, which distinguish from one another aldehydes, acids, ketones, alcohols, hydrocarbons, etc., are the results of very careful and extensive work by the author and his pupils. When the class to which a compound belongs has been determined, reference is made to a table of the species in this class, which are arranged according to melting- and boiling-points. The final identification of the substance is effected by the application of some characteristic test, or by the preparation of some easily prepared derivative, the physical properties of which can be readily determined. A great many of these specific tests for important compounds have been worked out with great care, and detailed directions are given for their application. To the reviewer these tests appear to be one of the most valuable features of the book. Two examples of the application of the method are given. The time required to identify a sample of hydroquinone was one hour and fifty minutes, and 0.85 gram of the substance was consumed. All the tests in the identification of mesitylene were completed in two hours and fifty-five minutes, with an expenditure of 0.87 gram of the substance.

In order to facilitate the identification of colored compounds, which constitute a suborder in the classification, the book is furnished with a color chart.

The final chapter is devoted to a consideration of the laboratory processes which are made use of in carrying out the various tests. These include the determination of melting-points, boiling-points, specific gravity, color, etc. Special attention is given to the methods employed in handling small quantities. This chapter is a valuable one, as in it are given a number of laboratory "wrinkles" which are not described elsewhere. In conclusion, the reviewer wishes to express the opinion that in giving to the chemical world this book, which is a record of eight years' work, most of which time was spent in the laboratory, Dr. Mulliken has made a valuable contribution to the literature of practical organic chemistry. J. F. N.

Reinforced Concrete.[1]

This little book is a translation and arrangement of a series of eight papers published in various periodicals during the past five years, by the well-known French engineer and experimenter, M. Considère, upon the subject of reinforced concrete, a subject which has attracted, probably, more attention during recent years than any modern development of structural engineering. The first of M. Considère's papers upon this subject was read before the Academy of Sciences in 1898, but this was followed quickly by others, until together they form a tolerably complete discussion of the experimental and theoretical aspect of the subject, and the translator has had for his object to rearrange and present them in logical form to the American reader, while adhering closely to the author's wording and treatment.

The first chapter treats of "reinforced concrete in bending." The experiments described really introduced compression as well as bending, but the former is comparatively small and has apparently been neglected. The discussion is, in parts, far from clear, and the reader will find it impossible to check the tables from the data given. These discrepancies, however, occur in the original papers, and it is to be regretted that the translator did not improve the opportunity to revise as well as to translate, and to eliminate some of these inaccuracies. Some of

[1] Experimental Researches on Reinforced Concrete, by Armand Considère; translated and arranged by Leon S. Moisseiff, C.E. New York: McGraw, 1903. $2.00.

the deductions appear very roughly approximate, especially as regards the coefficient of elasticity, the only reasonably accurate way to determine this quantity being by direct tests in compression and tension, and not from computations based on transverse tests, since the deflection clearly depends upon a number of elements. The general discussions, however, are interesting and valuable. One of the most surprising of Considère's results, as is well known, was that while in direct tension concrete will crack when the elongation reaches about 0.01 per cent., nevertheless, in reinforced beams the elongation on the tension side may be some ten times this value without any cracking. The author computes reinforced concrete beams using a constant value of E in compression (2,700,000 pounds per square inch) and a constant tensile stress on the concrete below the neutral axis, and assuming that plane sections remain plane.

In Chapter II the author discusses the deformation and testing of beams, and shows the uncertainty attending any attempt to compute deflections. Nevertheless, tests of the completed structure appear to be more necessary in the case of reinforced concrete structures than in the case of steel structures. The measurement of the local deformations — that is, of the direct compression or tension — will, perhaps, prove a better guide in this respect than the measurement of deflections, influenced as the latter is by shearing and other elements of the problem. In Chapter III the effects of changes in volume are considered, and the internal stresses which are thereby caused are discussed. This is a matter too often lost sight of in construction, and the bearing which these initial stresses have upon the use of rich concretes, the amount of water used, and other questions, merit careful consideration. In Chapter IV the tensile and compressive resistance of concrete is further discussed, and in Chapter V the resistance to shearing and sliding is briefly referred to. These questions, however, are yet in a quite uncertain state, and there is room for much further investigation regarding them. The effect of cracks is considered in Chapter VI, and finally, in Chapter VII, the subject of columns of reinforced concrete and the effect of using hoops are discussed at considerable length.

Altogether the book is a valuable and timely contribution to the literature of this important subject, and will be welcomed by all structural engineers. We only wish it had been made more clear in places, and free from inaccuracies in figures and tables. We hope these defects will be remedied in a future edition. G. F. S.